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Leucaena Research in the Asian–Pacific Region

Proceedings of a Workshop Held in Singapore, 23–26 November 1982

Organized by the Nitrogen Fixing Tree Association and the International Development Research Centre

Abstract

Because of *Leucaena leucocephala*'s multiple uses as forage, fuelwood, poles, green manure, etc., this fast-growing, nitrogen-fixing tree has been the subject of much research in the last decade. The results have clarified the capabilities of the plant as well as its limitations. One main constraint to cultivation in vast areas of Latin America and Southeast Asia has been leucaena's inability to survive on acidic, aluminum-saturated soils. At low pH, the aluminum complexes with calcium, which is essential for good growth. Trials have shown that some varieties of *L. diversifolia* can make use of the calcium from the complexes and that crosses between these varieties and *L. leucocephala* perform well on acidic soils. The main constraint to use of leucaena as a forage derives from the plant's content of mimosine, a toxic, nonprotein amino acid. Although leucaena has proved to be a highly nutritious animal feed, the mimosine and its breakdown product, DHP (3-hydroxy-4[1H]pyridone), have caused toxicity among animals fed high levels of leaf meal. Scientists now have evidence that the mimosine is converted into DHP when brought into contact with an enzyme contained in some of the plant's cells harbouring mimosine. This finding needs follow up; it suggests that simple processing, such as chopping fresh leaves, will convert all the mimosine into the less-toxic DHP. Elsewhere, researchers have found that DHP can be metabolized by anaerobic microorganisms that have been found in the guts of ruminants in countries like Indonesia. They have successfully transferred the microorganisms to animals in Australia where toxicity from DHP has deterred graziers from using leucaena as forage. Other research has defined optimal approaches to breeding and genetic improvement of leucaena, characteristics of rhizobia that effectively provide the plant with nitrogen-fixing ability; biomass production under widely different soil conditions; effects on fish, poultry, cattle, goats, and sheep fed leucaena leaf meal; management and cultural practices for both large-scale and smallholder operations; etc. The results are the subject of this publication, which comprises 30 papers from researchers in the Asian - Pacific Region.

Résumé

Leucaena leucocephala a fait l'objet de nombreuses recherches au cours de la dernière décennie, cet arbre légumineux fixateur d'azote et de croissance rapide ayant de nombreux usages comme fourrage, combustible, poteau, engrais vert, etc. Ces études ont permis d'en délimiter les fonctions. L'un des facteurs limitants de sa culture dans de vastes régions de l'Amérique latine et de l'Asie du Sud-Est est l'incapacité de *Leucaena* de survivre dans des sols acides, saturés d'aluminium. Dans le cas d'un faible pH l'aluminium complexe le calcium, essentiel à une croissance régulière. Des essais ont démontré que certaines variétés de *L. diversifolia* peuvent utiliser le calcium présent dans les complexes et que les croisements entre ces variétés et *L. leucocephala* prospèrent dans des sols acides. Le principal obstacle à l'utilisation de *Leucaena* comme fourrage est sa teneur en mimosine, acide aminé non protéique toxique. Bien que ce fourrage soit hautement nutritif, la mimosine et DHP (3-hydroxy-4[1H]pyridone) ont provoqué des cas de toxicité chez les animaux consommant de grandes quantités de farine de feuilles. Les scientifiques ont découvert que la mimosine se décompose en DHP lorsqu'elle entre en contact avec une enzyme contenue dans certaines cellules où elle est présente. Cette découverte a permis de déterminer des moyens simples de neutraliser cette substance toxique, tel que le hachage des feuilles vertes qui décompose la mimosine en DHP moins toxique. Ailleurs, des chercheurs ont trouvé que le DHP peut être métabolisé par des microorganismes anaérobiques présents dans l'intestin des ruminants dans certains pays comme l'Indonésie. Ils ont réussi à transférer ces microorganismes à des animaux en Australie où les pasteurs refusent l'emploi du fourrage de *Leucaena* à cause de la toxicité de DHP. D'autres recherches préconisent une approche optimale: de la sélection et de l'amélioration génétique de *Leucaena*; des caractères des rhizobiums qui assurent la fonction de la fixation d'azote chez la plante-hôte; de la production de bio-masse dans diverses conditions de sols très variés; des effets des rations de farine de feuilles sur les poissons, les volailles, le bétail, les chèvres et les moutons; de la gestion et des pratiques culturales des

opérations des petites et des grandes exploitations, etc. Tous ces résultats sont détaillés dans la présente brochure qui contient trente communications exposées par des chercheurs de la région du Pacifique asiatique.

Resumen

Debido a los múltiples usos de la *Leucaena leucocephala* como forraje, combustible, madera, abono, etc., este arbol, de rápido crecimiento y habilidad para fijar el nitrógeno, ha sido objeto de abundante investigación en la ultima década. Los resultados han aclarado las capacidades de la planta, así como sus limitaciones. Uno de los problemas para su cultivo en vastas areas de Latinoamérica y el Sudeste Asiatico ha sido su incapacidad para sobrevivir en suelos ácidos, saturados de aluminio. A niveles bajos de pH, el aluminio forma complejos con el calcio que es esencial para un buen crecimiento. Las pruebas han mostrado que algunas variedades de *L. diversifolia* pueden usar el calcio de los complejos y que los cruces entre estas variedades y la *L. leucocephala* se desempeñan bien en suelos ácidos. El principal inconveniente para usar la leucaena como forraje proviene de su contenido de mimosina, un aminoácido toxico no proteínico. Aunque la leucaena ha probado ser un alimento animal altamente nutritivo, la mimosina y su producto de descomposición, el DHP (3-hydroxy-4(1H)pyridone), han causado toxicidad entre los animales alimentados con altos niveles de harina de follaje. Los científicos tienen ahora evidencia de que la mimosina se convierte en DHP cuando entra en contacto con una enzima que se encuentra en algunas células de la planta que contienen mimosina. Este hallazgo necesita seguimiento, pero sugiere que un simple procesamiento, como picar las hojas frescas, convierte toda la mimosina en el menos tóxico DHP. En otras partes, los investigadores han encontrado que el DHP puede ser metabolizado por microorganismos anaerobicos que han sido hallados en el intestino de rumiantes en países como Indonesia. Ellos han traspasado con éxito los microorganismos a animales en Australia donde la toxicidad del DHP ha impedido que los ganaderos empleen la leucaena como forraje. Otras investigaciones han definido los enfoques óptimos para el fitomejoramiento de la leucaena, las características de la rizobia que efectivamente dotará a la planta de la habilidad de fijar nitrógeno, la producción de biomasa bajo condiciones edáficas ampliamente distintas, los efectos sobre los peces, las aves, el ganado, las cabras y las ovejas alimentadas con harina de hoja de leucaena, las prácticas culturales y de manejo para las actividades a gran escala o del pequeño agricultor, etc. Los resultados son el tema de esta publicación que abarca 30 trabajos de investigadores en la región Asiopacífica.

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Foreword

The great popularity of leucaena for the production of forage and fuelwood has prompted considerable research on the species since the first international consultation in 1976, which was held at Los Baños in the Philippines and was sponsored jointly by the Philippine Council for Agriculture and Resources Research (PCARR) and the National Academy of Sciences (NAS) of the United States.

The idea of holding a second international workshop on leucaena came up during the XVII World Congress of the International Union of Forestry Research Organizations (IUFRO), which was held in Kyoto, Japan, in September 1981. Discussions about possible cooperative activities were held between representatives of the International Development Research Centre (IDRC) and the newly created Nitrogen Fixing Tree Association (NFTA), and a decision was made to hold an international workshop in Asia in November 1982.

The main objectives of the workshop were:

- To summarize research and technological advances with leucaena that had taken place since the first international consultation;
- To prepare two manuals pertaining to leucaena wood production and forage production respectively;
- To assess major ecological and socioeconomic constraints to the production of leucaena as well as to evaluate the potential of other nitrogen-fixing species; and
- To identify research needs and priorities for development.

Invitations to participate in the workshop were sent to scientists and science administrators in Asian countries. They were asked to prepare papers on their research work or on other aspects of leucaena development in their respective countries. The response was most encouraging; in fact, it was not possible, because of physical and financial constraints, to bring together all the people who expressed an interest in attending the workshop. Nevertheless, the proceedings should be useful to all who wish to keep abreast of recent advances with leucaena, particularly in Asian countries.

Two small working groups of participants met at Los Baños in the Philippines for 3 days before the workshop to prepare two manuals — one on leucaena wood production and one on forage production. Also, two representatives of NAS attended the workshop and had discussions with participants for the specific purpose of obtaining new information to be incorporated in a revised edition of the very popular report *Leucaena: promising forage and tree crop for the tropics*, which was published in 1977, the same year PCARR produced the proceedings of the first international consultation on leucaena. The manuals, which will be published by NFTA, and the updated NAS report complement this publication. Interested readers are advised to write directly to the publishers to obtain copies.

IDRC wishes to express its gratitude to all the people who ensured the

success of this workshop and particularly to the participants who prepared papers and contributed to the discussions. In particular, it is most grateful to Professor James Brewbaker, President of NFTA, who organized the technical program of the workshop and to his associates who assisted in the task. It is hoped that the published proceedings will be of value to developing countries that are increasing their use of fast-growing, nitrogen-fixing trees to secure fuel, food, and fodder in their attempts to satisfy the basic needs of their people.

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Introduction

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Leucaena's spectacular increase in popularity over the last 10 years among agronomists, farmers, foresters, and timber people is mainly a reflection of trials that have shown it to be a unique, multipurpose crop, which has even been referred to as a miracle tree. The numerous plantings that have been made recently in subtropical and tropical areas have defined more accurately the advantages and limitations of leucaena. It is now apparent that the plant can make a significant impact on forage and wood production in a number of countries of Southeast Asia, the Pacific, and also Central and South America. At the same time, the factors preventing its successful exploitation in some areas are now more clearly understood.

Not all varieties are suitable for the uses proclaimed for the species. Multibranched varieties are suitable for forage; giant types are suitable for wood production: the two types have supplied the needs of discerning agronomists and timber producers. The widely spread, bushy common type is not particularly suitable for either use but is still planted in a number of areas, especially by the small farmer. There is a need for extension workers to ensure that smallholders, as well as large-scale producers, obtain seed of the best varieties along with the latest technological information.

In addition to its uses for forage and wood, leucaena has a strong appeal to the practical farmer for several reasons. One reason is the high seed yield and almost complete uniformity of populations in standardized varieties. Another is that the seed is very hard, which ensures longevity under a variety of conditions. With appropriate treatment, as with hot water, the seed normally germinates well. There is much discussion about methods of establishment, but direct seeding is cheaper and more practical than the use of potted seedlings. Unfortunately, direct seeding can be a disaster if weeds, ants, grazing animals, etc. are not controlled. With the advent of large-scale plantings for dendrothermal production of electricity, as in the Philippines, reliable establishment from direct seeding is urgently required. Seed needs pelleting with appropriate *Rhizobium* (to ensure nitrogen fixation), rock phosphate, and even sodium or ammonia molybdate.

Fear of mimosine toxicity among animals fed leucaena is still an obstacle to the use of the crop for cattle forage. Fortunately, recent Australian work has shown that mimosine and its breakdown product DHP (3-hydroxy-4[1H]pyridone) are completely decomposed by bacteria naturally occurring in the rumen of cattle in India, Indonesia, Hawaii, Brazil, and the Philippines. The DHP-decomposing bacteria that are missing in ruminants in Australia and other areas are being isolated and should soon be available for research. Thus, mimosine toxicity, as a problem in ruminants, will soon be a thing of the past.

Despite these successes with ruminants, mimosine and DHP still cause toxicity when leucaena is used in feed for chickens, pigs, and other nonruminants; therefore, efforts to breed and select varieties low in mimosine are still needed. The problem restricts leucaena leaf meal to 5–10% of the animals' diet. Treating the leucaena, especially the dry leaf, with aluminum or iron sulfates may inactivate the mimosine and allow the incorporation of higher levels of the legume in feed for monogastric animals.

There is a decided challenge, especially in Southeast Asian countries, to use the prolific seed yields of leucaena as a source of human food protein. A first step would be research on the fate of mimosine and DHP during the preparation of *tempe* and other foods.

Leucaena has proved very adaptable in a number of areas where the soil pH is greater than 5.5. However, there are substantial areas of more acid soils (pH 4.2–5.5) in Southeast Asia, and especially in South America, where current leucaena varieties will not grow satisfactorily. Of particular interest, therefore, is progress made in determining the soil factors involved and in finding adapted germ plasm

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that will cross with *Leucaena leucocephala* and impart tolerance to acid soils.

Because of the growth potential inherent in leucaena, a sensible approach is to adapt it to as wide a range of soils and conditions as possible through germ-plasm collection and breeding. There is much interest, for example, in obtaining leucaena types with the ability to grow in cooler, more elevated areas. *Leucaena diversifolia* and *L. esculenta* and their crosses with *L. leucocephala* appear to have distinct potential at higher elevations.

An important aspect that tends to be neglected in the cultivation of leucaena, whether on a small or a large scale, is its mineral nutrition. Leucaena is a tree legume with exceptional capacity to produce biomass and protein, provided it receives adequate nutrients. The balance of minerals in its leaves is an indication of the plant's nutritional health, and foliar analyses at the height of the growing season provide an essential basis not only for maintaining soil fertility but also for calculating productivity. Phosphorus, sulfur, calcium, magnesium, potassium, and minor elements like zinc are very important. Large-scale enterprises with leucaena cannot afford to neglect periodic monitoring of foliar mineral levels. If possible, this should be accompanied by suitable profile studies of minerals and pH in the subsoil. Costly failures could be avoided by these procedures, especially if combined with pilot studies.

The small farmer can control the mineral nutrition of the leucaena trees even without inputs of costly fertilizers. To counteract soil infertility in an area where leucaena is to be planted, he or she can dig rather deep and wide holes for the seedling and replace the soil after incorporating animal manure and lime or dolomite. It has been found that calcium in the form of lime, dolomite, and — preferably — gypsum will enhance the growth of leucaena, especially in acid soils.

Often, small farmers have hillside areas that, for subsistence, they cultivate intensely. As a result, erosion frequently becomes a hazard. Also, areas available for large-scale production in densely populated countries tend to be sloping, eroded, and wornout lands. Under both of these conditions, dense leucaena hedges, planted across the slopes, will reduce erosion problems and provide forage and fuel as well as green manure for associated crops. However, the establishment of leucaena on sloping, eroded land is not easy. It must be at the start of the wet season with generous use of artificial or animal manure in suitably prepared shallow trenches or mounds on the contour.

Growing crops like maize, cassava, and beans between leucaena hedges up to 5 m apart is becoming a popular practice. The leucaena hedges can, at various times, provide green manure for the crops, forage, and firewood but need to be properly maintained and integrated with crop requirements. For best results, the leucaena hedges need to be well fertilized at establishment, with phosphorus, sulfur, calcium, magnesium, potassium, and some minor elements. If possible, the leaf litter, or green manure, from the leucaena should be worked into the soil so that the crops can maximize the benefits from it. Crops receiving little or no fertilizer ordinarily show a 50% increase in yield when the leucaena hedge is introduced.

Research Priorities

Priorities for research on leucaena in Asia and the Pacific are in seed production, site adaptability, management, uses, pest control, and publications (Table 1). Within these general categories, the specific priorities of the countries in the region differ, as do their commitment to, and their funding for, future work on the species.

Australia

Research on leucaena in Australia will continue in the short term, although funding for long-term research is uncertain. Priorities include completing work on toxicity in ruminants (finding methods to inoculate animals with rumen bacteria that metabolize the breakdown product of mimosine, DHP), breeding leucaena varieties that can yield well under conditions of low rainfall and poor soil, and testing new, vigorous hybrids.

India

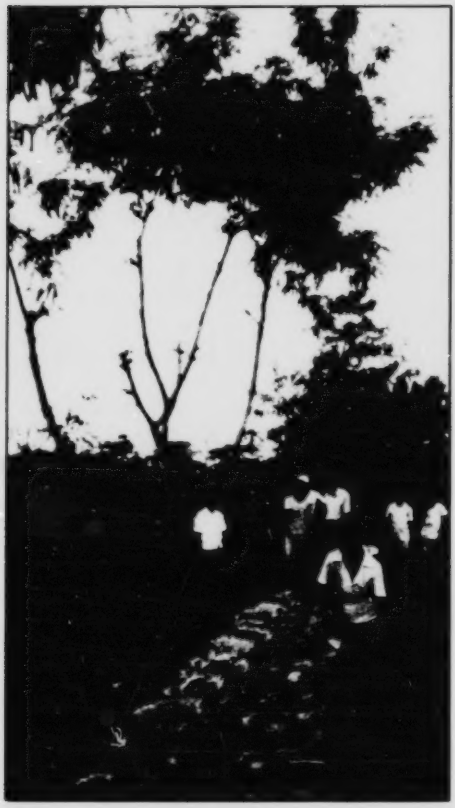
The greatest need in India now is for an adequate supply of good germ plasm to meet the growing demand. In addition, adaptability trials are needed in many locations for both wood and forage production. A particular focus for fodder research must be increased yields in the dry season. Studies of the control of diseases and pests, especially gummosis, are also needed. Other nitrogen-fixing trees (NFTs) and endemic species that can match some of the uses of leucaena should be investigated, and efforts should be made to raise the involvement of the private sector.

Indonesia

In Indonesia, species trials for fuelwood,

Table 1. Regional research and development priorities for leucaena in Asia and the Pacific.

	Priority		
	First	Second	Third
Seed production/ botany	Development of foundation-seed centres; variety trials	Vegetative propagation	Rhizobia and mycorrhizal associations; management for seed production
Site adaptability	Economic returns on fertilizer inputs; weed management, manual and herbicidal; foliar analysis as index of site quality	Site selection; relationship of growth to site parameters; establishment techniques	
Management	Coppice management; harvesting methods (economics and physiology); forage for small farmers;	Green manure	Thinning
Uses	Feed for nonruminants, fish, and fowl; household; industrial wood	Processing of forage and leaf meal; human food	National statistics base; calorific values; wood preservation
Pest and disease control			Ants; gummosis; mammals
Publications	Current research distributed internationally	Training packages and manuals	Smallholder-oriented periodical (upgrading of FORUM?)



In Sikka district, Indonesia, plots at the farmers' education centre (LPUT) include mixtures of leucaena and food crops.

forage, and other uses are considered a priority, particularly at the village level. A major need is effective communication of information to all parts of Indonesia. Because of the diverse conditions in the country, leucaena and other NFTs need to be tested in arid, humid, upland, and acid regions, especially in transmigration areas, and the use of leucaena as human food should be one focus. A centralized seed-production facility must be set up.

Malaysia

In Malaysia, where 85% of all livestock is owned by households or smallholders, the priority is to produce quality forage, especially shrub and tree forage. Like Indonesia, Malaysia needs a good source of seed of exotics like leucaena as well as endemic tree crops. In Sabah, identification of species with multiple uses is important, as is identification of good plantation species.

Nepal

Although leucaena is being grown in low elevations in Nepal, the greatest need at present is to identify NFTs that grow well at higher elevations and that can be managed to supply multiple uses: firewood, erosion control, and forage. Forage production is especially important to the villagers, and the introduction of trees is ideal for erosion control.

Pakistan

Watershed rehabilitation, soil conservation, and reforestation of arid areas are crucial in Pakistan. There are plans for the establishment of green shelterbelts for windbreaks, especially in the south, which is exposed to hot, desiccating winds. The shelterbelts will be used by rural dwellers for firewood and fodder. The role of leucaena in this program needs to be thoroughly studied.

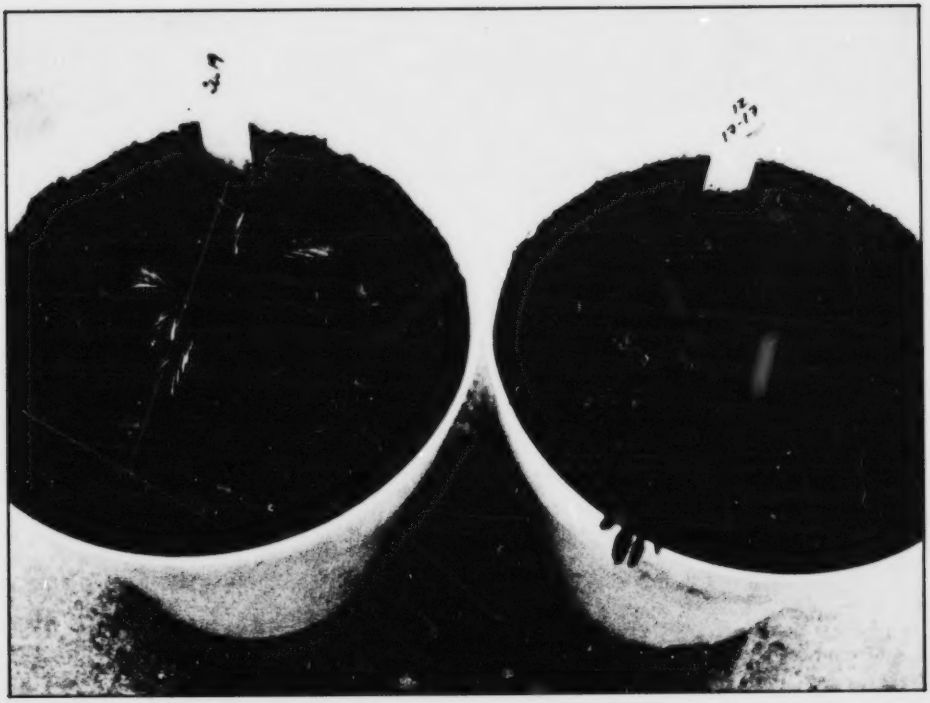
Taiwan

Taiwan has about 100 leucaena experiments under way and is in a position to share this information with interested researchers around the world. But funding could become a limiting factor for the maintenance of this active research. Local institutes would welcome collaborative studies funded by international development agencies. The focuses of research on wood production include harvesting and coppicing.

Thailand

Thailand's need is to integrate livestock raising and forestry. Leucaena is used for this purpose already, but information exchange both within and outside the country is necessary. Backyard pasture-cum-firewood mixes must be researched and developed, as must processed animal feed from leucaena, especially in mixtures with cassava.

Biology and
Improvement



A hybrid of L. leucocephala *and* L. diversifolia, *right, performs well on acid soils, whereas* L. leucocephala, *left, is stunted and yellow.*

Systematics, Self-Incompatibility, Breeding Systems, and Genetic Improvement of *Leucaena* Species

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Leucaena leucocephala *(Lam.) de Wit is an unusual tree from the standpoint of the plant breeder, for it is highly self-fertilized and polyploid (Brewbaker and Hutton 1979). Most tropical trees are largely cross-fertilized, and polyploidy is not common (Brewbaker and Styles 1982). In fact,* Leucaena *species other than* L. leucocephala *have been shown to be self-incompatible and, thus, highly cross-pollinated, with lower chromosome levels than* L. leucocephala. *These findings indicate that self-compatibility and chromosome level are linked in leucaena, as they are in many other legumes and flowering plants (Brewbaker 1954). The mechanism of fertilization, or the breeding system, determines the approach that plant breeders should take in genetic improvement and should be a primary consideration in methods of seed collection and multiplication. For example, breeders attempting to improve* L. leucocephala *should concentrate on selfed lines from outstanding hybrids or individual trees, planting seeds in small plots for yield trials. Multiline breeding is recommended. In contrast with* L. leucocephala, *the self-incompatible species are highly variable genetically, and the plots for yield trials must be isolated and large. The main opportunity for genetic advance is represented by half-sib selection and hybndization.*

Le Leucaena leucocephala *(Lam.) de Wit est un arbre assez inusité du point de vue du sélectionneur, parce qu'il est fortement autoféconde et polyploïde (Brewbaker et Hutton, 1979). La plupart des essences tropicales sont généralement à fécondation croisée et ne sont pas polyploïdes (Brewbaker et Styles, 1982). Des espèces de* Leucaena *autres que* L. leucocephala *se sont avérées autostériles et, donc, très sujettes à la fécondation croisée, avec un nombre de chromosomes inférieur à celui de* L. leucocephala. *Ces observations indiquent que chez* Leucaena, *l'autofertilité et le nombre de chromosomes sont reliés, comme ils le sont chez beaucoup d'autres légumineuses et plantes à fleurs (Brewbaker, 1954). Le mécanisme de fertilisation, ou le système reproductif, détermine l'approche que les sélectionneurs adoptent pour l'amélioration génétique, et ce point de vue devrait être une préoccupation majeure dans les méthodes de collecte des semences et de multiplication des sujets. Ainsi, les sélectionneurs désireux d'améliorer* L. leucocephala *devront se concentrer sur des lignées autopollinisées d'hybrides et d'arbres exceptionnels et en planter les semences dans de petites parcelles d'essais de rendement. On recommande les croisements par lignées multiples. En contraste avec* L. leucocephala, *les espèces autostériles sont extrêmement variables génétiquement et les champs d'essais devront être isolés et de grandes dimensions. La meilleure chance de progrès génétique semble résider dans l'hybridation et la sélection de demi-fratries.*

La Leucaena leucocephala *(Lam.) de Wit es un árbol extraño desde el punto de vista del fitomejorador porque es altamente autofertilizado y poliploide (Brewbaker y Hutton 1979). La mayor parte de los árboles tropicales son en buena parte de fertilización cruzada y el poliploidismo no es común (Brewbaker y Styles 1982). Se ha demostrado que la especie* Leucaena *distinta de la* L. leucocephala *es autoincompatible y, por tanto, de alta polinización cruzada, con niveles de cromosoma más bajos que la* L. leucocephala. *Estos hallazgos indican que la autocompatibilidad y el nivel cromosomático están vinculados en la* Leucaena *como lo están en muchas otras leguminosas y plantas que florecen (Brewbaker 1954). El mecanismo de fertilización, o el sistema de mejoramiento, determina el enfoque que los fitomejoradores deben adoptar para el mejoramiento genético y debe ser siempre una consideración básica en los métodos de recolección de semillas y multiplicación. Por ejemplo los mejoradores que intentan mejorar la* L. leucocephala *deben concentrarse en autopolinización de árboles individuales destacados y plantar las semillas en pequeños lotes para pruebas de rendimiento. Se recomienda el mejoramiento multilineal. Encontrarse con la* L. leucocephala, *las especies autoincompatibles son genéticamente muy variables y los terrenos para las pruebas de rendimiento deben ser aislados y grandes. La hibridación y selección de semi-hermanos representan la principal oportunidad de mejoramiento.*

The genus *Leucaena* has not been the subject of a definitive monograph, but a guide to its systematics is being completed (Brewbaker, in press, b). Many taxa have been attributed to this genus, but most of these are ill-defined or in doubt. There are at least 55

Table 1. Artificial key to the species of *Leucaena* Benth.

Leaflets very small (3–6 mm), numerous (20–60 pairs/pinna)
- Heads very large (>15 mm); leaves large (20–40 cm); pods large (18–25 cm); seeds large (>7 mm), rounded; young branches sharply angulate; bark corky, rough; flowering in winter ..... *L. esculenta* (1)
- Heads small (<12 mm); leaves small (10–30 cm); pods small (10–18 cm); seeds small (<5 mm), elongate; branches terete; summer flowering
  - Flowers white with very short calyx, few, in loose open heads; gland small, orbicular ..... *L. pulverulenta* (2)
  - Flowers pink (anthers, style) with compact head; gland large, oblong ..... *L. diversifolia* (3)

Leaflets intermediate in size (6–24 mm), fewer than above
- Leaflets quite large (8–24 mm), few per pinna (10–18); pinnae few per leaf (4–9)
  - Leaflets narrow (2–7 mm); pods wide (2 cm), commonly glabrous; glands large and cupular; large shrubs or trees (20 m) ..... *L. leucocephala* (6)
    - Shrubs or small trees (≤8 m); small leaves and leaflets (7–12 mm); small pods (12–18 cm); small seeds (5–7 mm) ..... var. *glauca*
    - Tall trees (18 m), large leaves and leaflets (10–18 mm); large pods (18–26 cm); large seeds (8–11 mm) ..... var. *salvadorensis*
  - Leaflets very wide (6–8 mm), squared at base; pods narrow (1 cm), commonly pubescent; glands small, rounded; low spreading shrub ..... *L. shannoni* (5)
- Leaflets smaller (6–9 mm), many per pinna (35–45); pinnae more per leaf (8–15) ..... *L. collinsii* (4)

Leaflets very large (20–60 mm), few per pinna (2–7 pairs)
- Flowers white, lacking bractlets; subtropical or tropical
  - Leaflets very large (5–7 cm); 2–5 pairs/pinna; flowers non-aromatic
    - Flower heads large (12–20 mm); wide pods (≥1.5 cm); Mexican trees ..... *L. macrophylla* (10)
    - Flower heads tiny (<8 mm) in terminal clusters; narrow pods (<10 mm); South American shrubs, trees ..... *L. trichodes* (9)
  - Leaflets smaller (2–4 cm), lanceolate; 6–7 pairs/pinna; flowers strongly scented; pods narrow ..... *L. lanceolata* (8)
- Flowers yellow, with long (>4 mm) yellow floret bractlets; small rounded leaflets; temperate ..... *L. retusa* (7)

published species epithets for the genus. My colleagues and I recognized but 10 of these a decade ago on the basis of our field trips and herbarium studies (Brewbaker et al. 1972). Our opinion has been verified by further study, which included growing all 10 species in Hawaii in the arboretum of 740 accessions (primarily from Latin America). The species hybridization clearly contributes to some taxonomic questions, and several species — notably *L. diversifolia* (Schlecht.) Benth. — are highly polymorphic.

Leucaena occurs in the tribe Mimoseae of the subfamily Mimosoideae (with about 2800 species) of the family Leguminosae. The subfamily is distinguished by its regular flowers and by traits such as an unusual base chromosome number (13 or 14). The tribe Mimoseae is further distinguished by having flowers with few stamens (5 or 10), nonoverlapping sepals, normally glandless anthers, and pollen grains that are shed singly (not in the polyads so common in this family).

The genus *Leucaena* is further distinguished as one of nonthorny trees and shrubs with flowers always in heads, pods with nonseparating margins, and transverse seeds. Its closest relatives appear to be the genera *Desmanthus*, *Mimosa*, and *Schrankia*. The unusual amino acid mimosine further distinguishes leucaenas. It is always present in leucaenas, ranging about threefold among the different species (Brewbaker and Kaye 1981). Mimosine was named, however, for the genus *Mimosa* in which it was first found and occurs sparingly.

The 10 species of *Leucaena* are characterized (Table 1) by their leaflets (Fig. 1) and flower heads. The large-leaved species appear to intergrade strikingly but are distinguishable from each other by several constant traits. Genetic variation is especially great within *L. diversifolia*, a taxon to which I attribute 13 species as synonymies.

Verified chromosome counts (somatic numbers) are $2n=52$ for *L. diversifolia*, *L. esculenta*, *L. lanceolata*, and *L. trichodes*; $2n=56$ for *L. pulverulenta*; and $2n=104$ for *L. leucocephala* (Brewbaker, in press, b).

Self-Incompatibility

Self-incompatibility (SI, popularly called self-sterility) is common among legumes. It is notable among perennial herbaceous genera, including *Trifolium*, *Lotus*, *Melilotus*, *Medicago*, and *Phaseolus*; it has also been observed, but is less well studied, in several woody genera, including *Caragana*, *Cytisus*, *Erythrina*, *Onobrychis*, and *Tephrosia*.

At the University of Hawaii, we have completed self-pollinations in all of the *Leucaena* species except *L. retusa* (Table 2). All plants tested in *L. leucocephala* were fully self-fertile. Most *L. diversifolia* plants were fully self-sterile, although a few were self-fertile. All other species were entirely self-sterile. Hutton and Eddie (1982) have also recorded the self-

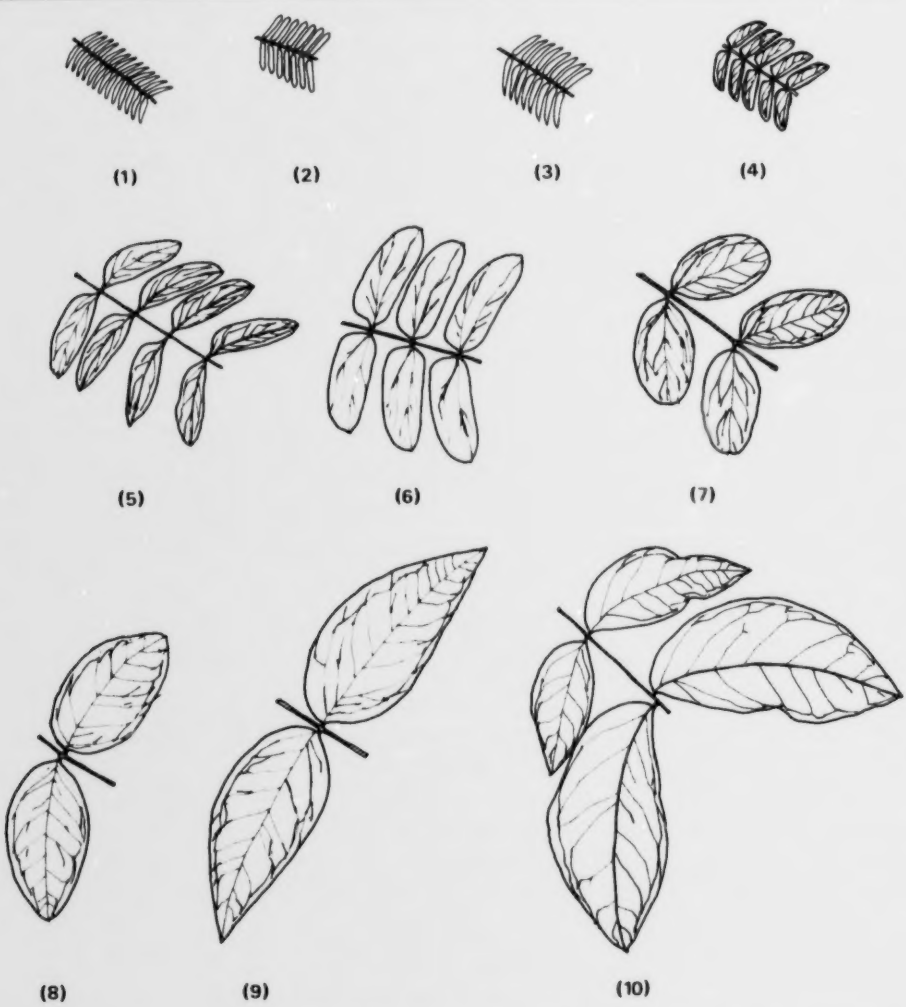

Fig. 1. Leaves of (1) L. esculenta, *(2)* L. pulverulenta, *(3)* L. diversifolia, *(4)* L. collinsii, *(5)* L. shannoni, *(6)* L. leucocephala, *(7)* L. retusa, *(8)* L. lanceolata, *(9)* L. trichodes, *(10)* L. macrophylla.

Table 2. Self- and cross-pollinations among *Leucaena* spp.[a]

	L. leucocephala	*L. diversifolia*	*L. shannoni*	*L. pulverulenta*	*L. macrophylla*	*L. lanceolata*	*L. esculenta*	*L. collinsii*	*L. trichodes*
L. leucocephala	SF 48/8	F 118/20	F 169/29	S 0/10	f 17/14	F 149/21	S 0/2	F 78/112	—
L. diversifolia	F 101/11	SI+SF 96/21	F 89/19	f 6/12	F 93/16	F 132/14	S 0/2	F 101/11	—
L. shannoni	f 3/11	f 4/20	SI 0/15	S 0/20	F 72/12	F 48/18	S 0/7	F 22/8	—
L. pulverulenta	F 105/10	F 45/16	F 64/11	SI 0/18	F 72/12	F 160/12	S 0/1	F 126/13	
L. macrophylla	S 0/2	F 15/1	S 0/1	—	SI 0/4	F 9/3	—	S 0/3	—
L. lanceolata	—	—	—	—	S 0/2	SI 0/15	—	—	—
L. esculenta	—	—	—	—	—	—	SI	—	—
L. collinsii	—	—	—	—	—	F 20/3	—	SI	—
L. trichodes	—	—	—	—	—	—	—	—	SI

[a] Data are numbers of pods formed over numbers of heads pollinated from 15 florets/head; F = high fertility; f = partial fertility; S = sterility; SI = self-incompatible; SF = self-fertile. Missing data will be added when results are available.

sterility of *L. trichodes* and *L. esculenta*. We pollinated all plants by carefully applying fresh pollen to the stigmas. Bagging the flowers without prior pollination prevents the production of seeds in all species except *L. leucocephala* (about 35% pod set). However, dichogamy occurs in *L. lanceolata* and *L. macrophylla*, with about 1 day lag between stigmatic receptivity and anthesis, and to a lesser extent in other species. Thus, simple bagging is a guide to self-sterility but is not definitive.

Investigated genetically, SI has been based on the operation of S alleles, or incompatibility alleles, of a single locus. Two basic systems occur, the more common being a "gametophytic type" that characterizes plants with binucleate pollen such as the legumes (Brewbaker 1967). Gametophytic incompatibility in diploids involves the presence in pollen and style of the same S allele; when the S allele in the pollen is not matched in the style, fertility occurs. *Leucaena* spp. could be expected to have the gametophytic type of self-incompatibility but may exhibit a two-locus system, reflecting the intrinsic polyploidy of the complex.

Why is *L. leucocephala* self-fertile? The answer must be associated with the polyploidy of this species. Atwood and I (1953; Brewbaker 1954) discovered that polyploid legumes and other plants may undergo "competition interaction." This interaction occurs in polyploids that produce pollen grains having two S alleles rather than one. When the two alleles are different, they can interact by competition, and the interaction leads to the breakdown of the self-incompatibility. Induced tetraploids of *Trifolium*, *Petunia*, and other genera often are self-fertile immediately upon doubling, even though their parent diploid clones are self-sterile. Other plants remain self-sterile upon doubling. The genetics of such populations favour self-fertility, with more than 50% self-fertility in newly derived tetraploid populations in species like *Trifolium repens* and *T. hybridum* (Brewbaker 1958). One important consequence of this type of gene action is that all polyploid plants derived by selfing (from self-fertile parents) will be self-fertile.

Leucaena leucocephala is thus believed to be self-fertile as a result of competition interaction between S alleles. This thesis leads to several important predictions:

- Occasional trees will be self-incompatible when either of two specific conditions is met: they are diploids (2n=52) or they are hybrids of 2n=104 trees with different S alleles.
- Most hybrids of *L. leucocephala* and other

species (triploids) will be self-fertile — a prediction we can already confirm for several crosses.

- Tetraploidy will induce self-fertility in other *Leucaena* species and may be the basis for the occasional self-fertile tree we have found in *L. diversifolia*.
- Clones derived from SI trees will be cross-sterile. Thus, they could serve as female parents for commercial ventures with attractive crosses like *L. pulverulenta* × *L. leucocephala* or *L. diversifolia* × *L. leucocephala*. The crosses can be expected to be fairly self-fertile, with depressed seed sets. They are not seedless (Gonzalez et al. 1967), although one could produce seedlessness by cloning SI plants — a possibility with potential for windbreaks and shade or avenue trees, where seediness is now an annoyance.

Hybridization

We have been crossing leucaenas sporadically for many years; Gonzalez et al. (1967) showed that several crosses were highly fertile, notably those involving *L. leucocephala* with *L. diversifolia* and *L. pulverulenta*. In the past 2 years, these crosses have been extended greatly by my colleagues Charles Sorensson and James Booman, to whom I owe thanks for data included in this review.

Pollination of the minute flowers of leucaenas is tedious but has been greatly simplified by the discovery of self-incompatibility, which obviates the need for emasculation. We thus initiate any study by a test of self-fertility. All flowers are bagged with small corn-shoot bags (ear bags), torn to fit over the branch to accommodate a staple. Bagging is made 1–2 days before anthesis. Anthesis is triggered by light and is delayed on cloudy days or by light-tight covers on the flower heads. Pollen dries quickly after dehiscence and is best used when freshly dehisced. A prediction not yet adequately tested is that the binucleate pollen of leucaenas will store quite well (Brewbaker 1967). We find the pollen viable after 1 day of storage but difficult to use. The copious, sticky pollen of species with large numbers of florets per head (*L. lanceolata*, *L. leucocephala*), is more easily used than the less-copious, dusty pollen of species like *L. diversifolia* and *L. pulverulenta*.

Sorensson and Booman have recorded year-round flowering for most species but very sparse winter flowering in Hawaii (20°N) for *L. collinsii*, *L. shannoni*, *L. lanceolata*, and the arboreal varieties of *L. leucocephala*. *Leucaena pulverulenta* has a very short summer flowering season; *L. macrophylla* and *L. trichodes* flower in late summer and autumn; and *L. esculenta* is winter flowering, restricting its use in pollinations here. *Leucaena retusa*, which does not nodulate in Hawaii's soils, has also not flowered. The strong floral fragrances of *L. shannoni* (baby-powder odour) and *L. lanceolata* (melon odour) prove highly attractive to bees, and care must be taken during hand pollinations to prevent the bees from pollinating the flowers.

Dichogamy of 1 day delays stigma receptivity in *L. lanceolata*, *L. macrophylla*, *L. trichodes*, and to a lesser extent in *L. leucocephala*. Although most species have stigmas emerging to the level of anthers or higher, the short stigmas of *L. lanceolata* are difficult to find and pollinate. Few pests bother pollinations, with some flower loss to psyllid insects and occasionally extensive seed loss to weevils (systemic insecticides like Cygon® prove effective in control).

We routinely pollinate 15 florets/head and often find that a head will support this full number of pods. Fertile crosses within species normally stabilize about 10 pods for the 15 florets. Crosses are empirically classified as fully fertile (F) if averaging more than two pods per cross and partially fertile (f) if fewer. The results of self- and cross-pollinations (Table 2) show an impressive extent of cross-fertility, as compared, for example, with herbaceous legumes. We plan to continue these studies through the years and grow all the fertile hybrids to maturity. Seed irregularities are common in many crosses, but pods apparently dehisce when there are no viable seeds developing in them. Hutton and Eddie (1982) note the fertility of crosses of *L. esculenta* × *L. leucocephala*.

Thus, gene transfer among the *Leucaena* spp. may be relatively easy, given the complexities of gene introduction into polyploids. Also, the heterosis of species crosses may be exploitable, as it has been in hybrid eucalypts, casuarinas, citrus, and pomes. In leucaenas, self-incompatibility may be a tool to produce crosses as marketable hybrid seeds in addition to exploitation of clonal propagation.

Phylogenetic relationships are little clarified as yet by our crosses, but it is customary at this stage of research to speculate on such relationships. I like to visualize *L. diversifolia* as a

complex central to evolution of many of the leucaenas and a probable parent (with *L. shannoni*?) of *L. leucocephala*. The common leucaena does not show quadrivalents at meiosis, and its chromosomes appear not to pair intergenomically with chromosomes of the 28-paired *L. pulverulenta* in hybrids (Gonzalez et al. 1967).

Impact of Breeding System

Genetic improvement of the self-fertile *L. leucocephala* should follow an approach that is completely distinct from that for the remaining self-sterile species. In *L. leucocephala*, the best initial progress will be made by researchers accessing outstanding individual trees and planting the seeds resulting from self-pollination. Genetic variability in leucaena progenies from single trees is small, and cross-pollination is suspected to be less than 2% (which is nonetheless high as a source of variability in populations). The low variability allows use of small-plot trials with minimal coefficients of variation, a unique trait for trees (Brewbaker et al. 1981).

Genetic advance cannot be made within pure lines, and little may be expected of "plus-tree" selection in populations of K8, K29, or other lines apparently tracing to single-tree selections. Selection in such lines must be viewed as roguing of off-type hybrids. Genetic advance among hybrid populations is predictable but is also predictably slow for this polyploid complex. Although leucaena is probably amphiploid, we have discovered no monogenic segregations in it, even with several isozyme markers, and suspect it to have high residual autoploidy. Genetic stability will, thus, require many generations of selfing, and success will depend on the use of large populations and intensive selection indices (e.g., in polyploids like sugarcane).

Multiline breeding should be considered for leucaena because the deployment of single-tree-derived progenies over large land areas raises the spectre of genetic problems. We have identified more than 50 different giant sources of leucaena and think it to be a very common trait in the species (probably also occurring in other species — Brewbaker 1980b). These could be consciously composited in specific frequencies by breeders to provide plantations having the different genotypes. On the other hand, it is quite probable that the common or Hawaiian-type leucaena that is adapted widely throughout the tropics can be traced to a very restricted gene source, possibly one tree in western Mexico. Polyploidy can provide major buffering against evolution of monogenic diseases, as an example (Brewbaker, in press, a).

The self-incompatible species of *Leucaena* present an entirely different target to seed producer, collector, or breeder. Like corn, these will be highly variable genetically from tree to tree and will need full isolation to produce improved seeds. Seeds from any one tree will represent only 50% of that tree's germ plasm, and any provenance collection in nature should represent many trees in an interbreeding population. Large plots will be needed for yield trials. Genetic progress will be rapid only through exploitation of hybrids or by hand pollination leading to full-sib progenies for routine evaluation of combining ability.

Opportunities for great genetic advance are, nonetheless, available immediately in the SI species of *Leucaena*, perhaps at first with only half-sib mating techniques. The ease with which populations can be coppiced to produce matings of selected trees should be exploited. Cloning would naturally accelerate the identification of superior trees and permit establishment of seed orchards with outstanding combiners. We have embarked on such a selection program with arboreal *L. diversifolia*, among which self-fertility is also known. Commercial exploitation would appear a possibility with this species, with hybrids involving *L. pulverulenta* and, possibly, *L. macrophylla* and *L. esculenta* (of highlands). The rapid seed-to-seed turnover, abundant seeds, ease of planting and coppicing, and rapid growth of all of these species bode well for their development as commercial species in the future.

Selection and Breeding of Leucaena for Very Acid Soils

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For satisfactory growth of Leucaena *in oxisols, and presumably ultisols, efficient root absorption of Ca, allowing deep-root penetration into subsoils, is more important than Al tolerance of roots. The acid-soil-tolerant lines are able to absorb sufficient Ca for prolific root growth in spite of the presence of high exchangeable Al. Increase in the subsoil Ca supply from surface applications of lime, dolomite, and $CaSO_4$ is slow and not to the depths required for extensive exploitation of subsoils for water and minerals by leucaena roots. Among the Ca sources, $CaSO_4$ provides both Ca and S and a better downward movement of Ca.*

The techniques that have been developed have enabled the selection of acid-soil-tolerant leucaena lines. This has enabled crosses to be made in which the acid-tolerance character has been transferred. Chromosome studies are needed, as it seems that, for best field results, it is necessary to have the acid-tolerance character in an L. leucocephala *background. The adaption of leucaena to the oxisols and the ultisols of South America can now be achieved.*

Pour obtenir un développement satisfaisant du Leucaena *dans les oxysols, et sans doute aussi les ultisols, l'absorption satisfaisante du Ca grâce à la pénétration profonde du sous-sol par les racines revêt plus d'importance que la tolérance des racines à Al. Les lignées tolérantes aux sols acides peuvent absorber suffisamment de Ca pour développer un système radiculaire abondant, malgré la présence de beaucoup de Al échangeable. L'amélioration des réserves de calcium du sous-sol par des applications en surface de chaux, de dolomite, et de $CaSO_4$ est lente et n'atteint pas les profondeurs nécessaires à une utilisation extensive de l'humidité et des minéraux du sous-sol par les racines du* Leucaena. *Parmi les sources de Ca, $CaSO_4$ apporte à la fois Ca et S et facilite la migration du Ca vers le sous-sol.*

Les techniques explorées jusqu'ici ont permis la sélection de lignées de Leucaena *tolérantes aux sols acides ce qui, à son tour, a permis d'effectuer des croisements dans lesquels ce caractère a pu être introduit. Des études de chromosomes s'imposent : il semble en effet que pour obtenir les meilleurs résultats pratiques, le caractère de tolérance à l'acidité doive se retrouver dans les antécédents de* L. leucocephala. *On peut réussir maintenant à adapter le* Leucaena *aux oxysols et ultisols sud-américains.*

Para el crecimiento satisfactorio de la Leucaena *en oxisoles, y presumiblemente en ultisoles, la eficiente absorción radical de Ca, que permita une penetración profunda de la raíz en los subsuelos, es más importante que la tolerancia de la raíz a Al. Las líneas tolerantes a los suelos ácidos pueden absorber suficiente Ca para un crecimiento prolífico de la raíz a pesar de la presencia de Al altamente intercambiable. El aumento en el Ca del subsuelo a partir de aplicaciones superficiales de cal, dolomita y $CaSO_4$ es lento y no a la profundidad requerida para una explotación extensa de los subsuelos por agua y minerales por las raíces de* Leucaena. *Entre las fuentes de Ca, $CaSO_4$ proporciona tanto Ca como S y un mejor descenso de Ca. Las técnicas desarrolladas permiten la selección de líneas de* Leucaena *tolerantes a los suelos ácidos. Esto ha permitido hacer cruces en los que se ha transferido la tolerancia al ácido. Se necesitan estudios de cromosomas puesto que parece que, para mejores resultados, es necesario tener la tolerancia al ácido en el antecedente de una* L. leucocephala. *La adaptación de la* Leucaena *a los oxisoles y los ultisoles de Suramérica puede ahora lograrse.*

South America has the largest area of very acid soils in the world, consisting of more than 8.0×10^8 ha of oxisols and ultisols with a pH about 4.5 and aluminum saturation of about 85% (Sanchez and Salinas 1981). It includes the Llanos of Colombia and Venezuela, the Amazon of Brazil and Peru, and the Cerrados of Brazil. In these areas, there is considerable interest in obtaining leguminous trees, especially *Leucaena*, for the production of wood and forage. Agroforestry systems based on edible leguminous trees would, in the Amazon, reduce the problems that follow forest clearing as well as supplying necessary protein for cattle. In the Cerrados, these systems would relieve the critical dry-season shortage of feed protein.

After the Amazon forest has been cleared and burned, there is a migration of ash minerals toward the subsoil. Under these conditions, such as near Manaus, Cunningham leucaena grows satisfactorily for some years. However, calcium deficiency can be expected

when the roots penetrate into the very acid subsoils.

Cunningham, Peru, and other *L. leucocephala* varieties, including the giants, have given poor growth in the oxisols of the Llanos, as at Carimagua, and in the Cerrados as at Brasilia. Early growth from applied fertilizer, including superphosphate, dolomite, potash, and minor elements, is good, but growth is retarded by the end of the season. Root development is superficial and mainly in the fertilized layer, with deep penetration being prevented by factors associated with the high subsoil acidity. These factors were considered principally to be high exchangeable Al and low Ca levels.

Researchers at the Centro Internacional de Agricultura Tropical (CIAT) originally concentrated on selection of leucaena for Al tolerance in sand culture containing all essential nutrients and Al at 5 ppm. Variable populations were studied from second- and third-generation seed of a Cunningham–*L. pulverulenta* F_1 backcrossed twice to Cunningham. From 45 000 seedlings evaluated, 12.6% were selected for Al tolerance. When the selections were grown in Carimagua oxisol in the glasshouse with restricted fertilizer applications, only one-fourth grew satisfactorily. Foliar analyses proved that Al levels were usually below 200 ppm and that P (0.15%) and Mg (0.2%) levels were normal. However, Ca contents were low (0.14–0.24%) in those with poor, yellowish growth and poor nodulation and medium (0.4%) in the small proportion with good, green growth and good nodulation.

The most promising *Leucaena* hybrids from the glasshouse trials were grown in the field at Carimagua with appropriate fertilizer and with Cunningham as control. None of the selections grew more than 1 m high, and all developed yellowish leaves, with Al at less than 200 ppm. It was apparent that their medium root absorption of Ca was not high enough to give good root and top growth in the Carimagua oxisol, even with adequate fertilization. These results clearly indicated that Al per se was not the major problem and that higher root absorption of Ca against the antagonism of high exchangeable Al was necessary for good leucaena growth in oxisols.

Superior Adaptation

It did not appear possible to obtain high tolerance to oxisols among current leucaena varieties, so it was necessary to investigate a range of different types. A number of Brewbaker introductions from Central America of species other than *L. leucocephala*, as well as *L. leucocephala* controls including Cunningham and some giants, were grown simultaneously in Carimagua oxisol in the glasshouse and in the field at Carimagua.

Important findings resulted from this investigation:

- Natural interspecific crossing had taken place in some species, notably *L. diversifolia*, *L. esculenta*, *L. macrophylla*, *L. pulverulenta*, and *L. shannoni*. These are all self-incompatible and have 2n=52 chromosomes, except *L. pulverulenta* with 2n=56 chromosomes. The natural hybrids were relatively easy to identify and, in the field-grown populations, constituted about 90% in *L. esculenta* and *L. shannoni*, 6–17% in *L. macrophylla* and *L. pulverulenta*, and 1.5–9% in *L. diversifolia*. All the natural hybrids, except those of *L. esculenta*, were fertile. The majority had chromosome numbers about 2n=78, indicating that the main natural crossing was with *L. leucocephala* with 2n=104 chromosomes. *Leucaena trichodes*, also self-incompatible with 2n=52 chromosomes, exhibited no natural interspecific crosses and appeared genetically isolated. *Leucaena collinsii*, with apparently 2n=102 chromosomes, did not show any definite natural crosses, but this possibility needs further investigation.
- High acid-soil tolerance was exhibited by *L. diversifolia*, *L. macrophylla*, *L. shannoni*, and their natural hybrids. The two *L. diversifolia* lines were relatively uniform for high tolerance, whereas *L. macrophylla* and *L. shannoni* were variable for high tolerance. In the field at Carimagua, these tolerant lines remained green and grew 3 m high by the end of the 2nd season. The *L. leucocephala* controls became yellow and were no more than 1 m high, although one giant with high Al tolerance reached 1.5 m high. Foliar analyses showed that Al levels in the *L. leucocephala* controls and the highly tolerant lines were no more than 170 ppm. However, Ca contents in *L. leucocephala* were 0.4% or less, 0.6% in *L. diversifolia*, and 0.72% and 0.74%, respectively, in the *L. macrophylla* and *L. shannoni* hybrids. Root excavations to a depth of 1 m

or more showed superficial rooting in *L. leucocephala* lines. In *L. diversifolia*, a high proportion of the trees remained green and vigorous, and most of these had deep thick roots that continued into the subsoil. In *L. macrophylla*, *L. shannoni*, and their hybrids, relatively small numbers of trees were green and vigorous, and most of these also had deep penetration of thick roots into the subsoil.

- Intolerance to acid oxisols occurred in *L. collinsii*, *L. esculenta*, *L. trichodes*, and *L. pulverulenta* populations with intense yellowing and death of a proportion of the trees in both glasshouse and field. In the two *L. pulverulenta* lines, a low proportion of hybrid trees proved to be tolerant and the progenies of these are now giving promising results in the Carimagua oxisol. Further introductions of *L. diversifolia* proved to have low acid-soil tolerance, so high tolerance is not a feature of all *L. diversifolia* lines.

Natural and Hand-Made Interspecific Hybrids

A number of promising natural interspecific hybrids have been selected in *L. diversifolia*, *L. macrophylla*, and *L. shannoni* and also in *L. pulverulenta* (Hutton 1981). Because they are fertile, further field trials in the acid oxisols at Carimagua and Brasilia have been possible as well as intensive glasshouse evaluation in the Carimagua oxisol.

As a corollary to this work, hand crosses have been made between *L. diversifolia* and *L. shannoni* on the one hand and *L. leucocephala* Cunningham and the giant K420 on the other. Because of flowering problems, no crosses were obtained between *L. macrophylla* and *L. leucocephala*. The acid-intolerant *L. esculenta* was crossed successfully with *L. leucocephala*, but this did not prove possible with the acid-intolerant *L. trichodes*.

The hand-made interspecific hybrids with *L. diversifolia* and *L. shannoni* have proved fertile, as in the natural ones. Their chromosome numbers are mainly intermediate, 2n=78. Flower head and leaflet size are also intermediate between these species and *L. leucocephala*. *L. diversifolia* flower heads often are deep rose, so, in some of the *L. diversifolia* crosses, a proportion of the flower heads were light rose.

In the breeding of acid-soil-tolerant leucaenas for the very extensive oxisol and ultisol areas of South America, it appears necessary to transfer the high-acid tolerance of *L. diversifolia* or *L. shannoni* into an *L. leucocephala* background.

This has a number of advantages, including self-pollination, high seed production, and stability of the populations, as well as high potential for wood and forage production. *L. diversifolia* wood tends to be brittle, a character to be avoided. However, apart from its acid-soil tolerance, *L. diversifolia* could confer its rapid early growth, which would be important in field establishment.

In glasshouse investigations, the high acid-soil tolerance of *L. diversifolia* and *L. shannoni* has been transferred in the F_1 of the crosses with *L. leucocephala*. The F_2 populations of these crosses are now being investigated for tolerance, with particular attention to chromosome levels. Whether it will be necessary to backcross to *L. leucocephala* to raise chromosome numbers to 2n=104 is not known at present.

Factors Affecting Breeding

The main factors that breeders must deal with when attempting to produce leucaena adapted to acid oxisols and ultisols are:

- Soil pH 4.2–4.5, Al saturation 80–90%, soil solution Al 4–5 ppm.
- Deficiencies of P, S, Ca, Mg, K, and micronutrients like Zn; Ca saturation less than 20% except in the deepest horizons.
- Surface applications of P remain in the surface, whereas those of Ca and Mg move slowly downward to the subsoil. Ca in $CaSO_4$ has a better downward movement than Ca in lime or dolomite (Ritchey et al. 1980).
- In plants, all important mineral nutrients, except Ca, are translocated to both tops and roots. Ca is translocated only to plant tops, where it is immobilized in old leaves (Mengel and Kirkley 1978).
- Essential characters are associated mainly with the roots. Roots need to prevent excess Al absorption or to detoxify absorbed Al. Roots will not grow without Ca. For the roots to grow and penetrate the acid subsoils, they need to absorb Ca efficiently from the low amounts available, in spite of the presence of high exchangeable Al.

Most of the work on selection of acid-tolerant leucaena lines and hybrids has been done in the Carimagua oxisol in either the

glasshouse or the field. In the soil profile at Carimagua, there is a zone from about 0.20–1 m deep that has very unfavourable conditions for root growth because of the high Al saturation and low Ca saturation. Deeper than 1 m, there is an increase in pH and Ca and a decrease in Al saturation, so that conditions are more favourable for root growth.

The glasshouse evaluations for acid-soil tolerance have been done in soil from the unfavourable zone at Carimagua, i.e., with high Al saturation and low Ca saturation. The glasshouse selections, with green, vigorous top growth and long prolific roots that are well nodulated, are the ones with high acid-soil tolerance. Those with poor, yellowish top growth and poor root growth and nodulation lack acid-soil tolerance. Root damage from Al was not apparent in any of the lines, even in the intolerant ones with poor growth. It seems that the roots of intolerant lines, however, are unable to grow because of insufficient absorption of Ca caused by the antagonistic effect between Al and Ca at the root surface. Why the lines with high acid-soil tolerance are able to absorb sufficient Ca for prolific root growth, in spite of the high Al saturation, is the key question that needs answering.

There is a good correlation between the reactions of acid-soil-tolerant and intolerant lines in the glasshouse and in the field at Carimagua. It is apparent that the roots of those leucaena lines with efficient Ca absorption are able to grow through the unfavourable subsoil zone into the deeper, more favourable zones. This results in green, vigorous top growth, with trees up to 3 m high by the end of the 2nd wet season. Glasshouse evaluation can accelerate the selection of acid-soil-tolerant leucaena lines. In 3 months in the glasshouse, a large number of lines can be evaluated for acid-soil tolerance — evaluations that would take up to 2 years in the field.

Other oxisols, such as those in the Cerrados and Amazon of Brazil, have similar characteristics to the Carimagua profile. Although the favourable zone for root growth in these is deeper (1.5–2 m) than that at Carimagua, preliminary results indicate that acid-soil-tolerant leucaena lines, selected at CIAT in the Carimagua oxisol by the methods outlined, will also grow well in the field in the typical Cerrados oxisol at Brasilia. Similar results are expected in the Amazon. Field evaluations of promising selections have not been made as yet in a typical ultisol, as at Pucallpa in Peru. However, the results could be satisfactory, as the subsoil Ca levels are almost double those in the oxisols.

To date, sufficient hand crosses have been made to combine the best characters of Cunningham cultivar and the giant K420, respectively, with the most acid-soil-tolerant selections from *L. diversifolia* and *L. shannoni*. It is now necessary to make acid-tolerant selections within the F_2 populations from these crosses in oxisols, both in the glasshouse and in the field. Current results indicate that high-yielding forage and wood types of leucaena with high acid-soil tolerance are now a definite possibility.

Nodulation, Nitrogen Fixation, and *Rhizobium* Strain Affinities in the Genus *Leucaena*

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Leucaena spp. belong in the subfamily Mimosoideae of the Leguminosae. All 10 species have been reported to nodulate readily, but some doubt remains in the case of L. retusa, which has failed to nodulate in Hawaii soils. The infection process has not been studied in leucaena. Nodule shape is variable, being astragaloid, desmodioid, or muconoid in form. Attachment to the root is narrow and fragile. Annual nitrogen accumulation rates of 600 kg/ha and as high as 1 t/ha are on record, but annual nitrogen fixation has not been determined with precision. One approximation, based on the acetylene-reduction technique, puts annual fixation at 110 ± 30 kg. The specific designation for the leucaena rhizobia is Rhizobium loti. These rhizobia are typically fast growing, gummy, and translucent on yeast-mannitol agar (YMA). They are neutral, or slightly acidic, in the pH reaction on YMA. Leucaena rhizobia will nodulate other tropical legumes usually nodulated by fast-growing rhizobia and will also nodulate some species normally nodulated by slow growers. Slow-growing strains of Rhizobium from other tropical genera do not nodulate leucaena.

Leucaena usually nodulates spontaneously with indigenous soil rhizobia without specific inoculation, but the documented cases of nodulation failure are sufficient to prompt adoption of legume inoculation when leucaena is introduced to locations where it has not been grown before. Although leucaena performs very poorly in acid-soil sites, strains of Rhizobium for leucaena are available that exhibit tolerance to low pH. Acid tolerance in a strain is not dependent on an alkali-producing capability. One particular strain, TAL 1145, has proved to be competitive for nodule formation, persistent in the soil microflora, and fully effective as a nitrogen-fixing partner for leucaena in acid soils.

Leucaena spp. appartient à la famille des mimosacées, sous-famille des légumineuses. Il a été constaté que toutes les 10 espèces forment aisément des nodosités mais il subsiste quelque doute au sujet de L. retusa qui n'en produit pas dans les sols d'Hawaii. Le processus d'infection n'a pas été étudié chez Leucaena. La forme des nodosités varie et peut être astragaloïde, desmodioïde ou muconoïde. Le point d'attache à la racine est étroit et fragile. Les quantités d'azote atmosphérique accumulées annuellement atteignent 600 kg/ha et l'on en a rapportées de 1 t/ha, mais la fixation annuelle n'a pas été établie avec précision. Une approximation fondée sur la technique de réduction à l'acétylène évalue la fixation annuelle à 110 kg ± 30 kg. La désignation spécifique du rhizobium de Leucaena est Rhizobium loti. Ces bactéries ont un développement typiquement rapide, et apparaissent gommeuses et translucides sur agar de levure-mannitol (YMA). Elles sont neutres ou légèrement acidulées dans la réaction du pH sur YMA. Le rhizobium de Leucaena formera des nodosités sur d'autres légumineuses tropicales généralement réceptives aux nodosités produites par des rhizobiums à croissance rapide, et il en produira également sur certaines espèces normalement réceptives à des rhizobiums à plus lent développement. Les souches de Rhizobium à développement lent provenant d'autres espèces tropicales n'inoculeront pas le Leucaena.

En général, Leucaena forme spontanément des nodosités avec les rhizobiums indigènes, sans inoculation particulière. Mais les cas vérifiés de nodulation manquée sont assez fréquents pour faire adopter l'inoculation de la légumineuse lorsqu'on introduit Leucaena dans des endroits où il n'a jamais été cultivé. Bien que celui-ci se comporte très médiocrement dans les régions à sols acides, il existe des souches de Rhizobium tolérantes à l'égard d'un faible pH. La tolérance d'une souche à l'acidité ne dépend pas d'une aptitude à produire des alcalis. Une souche particulière, TAL 1145, s'est révélée compétitive pour la formation de nodosités, persistante dans la microflore du sol et tout à fait efficace comme partenaire fixateur de l'azote pour Leucaena, en sols acides.

La especie Leucaena pertenece a la subfamilia Mimosoideae de las leguminosas. Se ha informado que todas las 10 especies nodulan prontamente, pero hay todavía dudas en el caso de la L. retusa, que no ha nodulado en los suelos de Hawaii. El proceso infeccioso no ha sido estudiado en la leucaena. La forma del nódulo es variable, siendo astragaloide, desmodioide o muconoide. El agarre a la raíz es delgado y frágil. Se han registrado casos de acumulación anual de nitrógeno de 600 kg/ha y hasta 1 t/ha, pero la fijación anual de nitrógeno no ha sido determinada con precisión. Una aproximación, con base en la técnica de reducción por acetileno, señala la fijación anual en 110 ± 30 kg. La designación específica para la leucaena rizobia es Rhizobium loti. Estas son rizobias de rápido cre-

cimiento, gomosas y translúcidas en agar manitol-levadura (YMA). Son neutras, o ligeramente ácidas, en la reacción del pH en YMA. La rizobia de la leucaena nodulará otras leguminosas tropicales normalmente noduladas por rizobias de rápido crecimiento y también nodulará algunas especies noduladas lentamente. Las líneas de crecimiento lento de la rizobia de otros géneros tropicales no nodulan la leucaena. La leucaena nodula por lo general espontáneamente con rizobia de suelos nativos sin inoculación específica, pero los casos documentados de fracaso de nodulación son suficientes para promover la adopción de inoculación de la leguminosa cuando la leucaena se introduce en localidades donde no se ha sembrado antes. Aunque la leucaena se desempeña muy pobremente en suelos ácidos, se encuentran líneas de Rhizobium *para leucaena que exhiben tolerancia al pH bajo. La tolerancia al ácido en una línea no depende de la capacidad de producción alcalina. Una línea particular, TAL 1145, ha demostrado ser competitiva en la formación nodular, persistente en la microflora de los suelos, y totalmente efectiva como socio fijador de nitrógeno para la leucaena en suelos ácidos.*

The genus *Leucaena* belongs taxonomically in the subfamily Mimosoideae of the Leguminosae. In common with the majority (84%) of the genera in this subfamily, *Leucaena* includes species that are known to bear root nodules (Allen and Allen 1981). These nodules, formed after infection of the roots by compatible strains of the soil bacterium *Rhizobium*, confer leucaena with the ability to fix atmospheric nitrogen. Autosufficiency in nitrogen supply through the process of biological nitrogen fixation (BNF) is a highly desirable trait in any plant. Leucaena's BNF capability undoubtedly contributes to its rapid growth and to its success as a colonizing species on poor soils.

Nodulation

As recently as 1979, all nodulating legumes were presumed to become infected with *Rhizobium* by a process involving penetration of root hairs (Bauer 1981). Root-hair curling, resulting in a characteristic shepherd's crook appearance, and the development of infection threads have been considered prerequisites for nodulation. But, in reality, infection threads have been observed in only a few species and are only presumed to occur in others. Some tropical legumes, initially thought not to have root hairs, have been studied to determine their mode of infection. *Arachis hypogaea* (Chandler 1978) and *Stylosanthes guianensis* (Dart, Roughley, and Date, as quoted in Bauer 1981) have been shown to nodulate after penetration of the root at the junction of the root hairs and cortical cells. Root hairs in these species are concentrated around the points of emergence of lateral roots, and, consequently, these are the loci at which nodulation occurs. The leucaena–*Rhizobium* symbiosis remains to be elucidated. One obstacle to progress in this area is that leucaena has a rapidly growing taproot that does not lend itself to the standard methods used for observing infection.

Nodule morphology is variable in leucaena. The first nodules forming on the taproot are usually spherical, but elongated, branched, or even coralloid nodules have also been observed. Although coralloid nodules have been recorded with a span of more than 3.0 cm, lateral dimensions of 0.5–1.0 cm are more common. The attachment of the nodule to the root is narrow, not girdling the root. This fragile attachment could well be a factor contributing to the infrequency with which nodules have been observed on the excavated roots of mature leucaena trees.

The variability in nodule form is underscored by the array of nodule-descriptive codes (Corby 1980) that have been attributed to the nodules of the single species *L. leucocephala*. In each of four publications, different basic nodule shapes were reported. Based on these reports, leucaena nodules can be described under Corby's classification as astragaloid, desmodioid, or muconoid.

Nodules are most commonly described for seedlings because of the difficulties involved in extricating the root systems of mature trees from field soils. Many researchers have reported informally that they have been unable to observe the presence of nodules on leucaena more than a year old. Thorough description of the distribution, quantity, and nitrogen-fixing effectiveness of nodules on root systems of mature leucaena specimens is lacking. This information is essential for definitive calculation of the quantity of atmospheric nitrogen fixed by leucaena.

Nitrogen Fixation

Leucaena leucocephala has been credited with some of the highest figures for annual nitrogen fixation ever recorded. But interpretation of the high levels purported to occur must be tempered by an appreciation of the precision with which nitrogen fixation per se, as opposed to soil-nitrogen uptake, can be de-

termined. For example, an exceptionally high figure for annual nitrogen fixation, 1 t N/ha (Dijkman 1950), was actually the accumulation of nitrogen in leafy matter of trees in a leucaena plantation harvested bimonthly for a 1-year period. This figure cannot be attributed solely to BNF because soil nitrogen also contributed to the total. The often-quoted annual values of 500 kg N/ha given by Guevarra (1976) for K8 leucaena and 600 kg N/ha for K341 leucaena are also total-nitrogen *accumulation* in the forage fraction.

The precise annual nitrogen *fixation* by leucaena remains to be determined. Deriving such a value is especially complex in a tree legume. In approximation methods, a nonleguminous crop is usually grown alongside a legume. Then, nitrogen accumulation in the nonlegume is assumed to be the soil contribution. This is subtracted from the total accumulation in the legume as an estimate of the nitrogen gain through fixation. But, with leucaena and other nitrogen-fixing trees, this approach is confounded by lack of an appropriate perennial nonleguminous crop for comparison.

The more precise methods, in which isotopic nitrogen is incorporated in the soil for measurements of the legume's soil-nitrogen uptake, are difficult to accomplish because of the depth and total volume of soil explored by tree roots.

In a recent study with *L. leucocephala* in Tanzania (Hogberg and Kvarnstrom 1982), rough calculations, based on acetylene-reduction rates in nodule tissue, gave a figure for annual nitrogen fixation of 110 ± 30 kg/ha. The calculation was based on experimentally derived values for nodule biomass and specific-nodule nitrogenase activity but involved crude assumptions for the ratio of acetylene reduced to nitrogen fixed and for the seasonal fluctuation in nodular activity. No correction for diurnal variation in nitrogenase activity was attempted. Each of these factors is researchable. Thus, it should be possible to arrive at a sounder figure for annual nitrogen fixation in leucaena using approaches such as those found satisfactory for other perennials (Halliday and Pate 1976a,b).

Rhizobia Affinities

The rhizobia for the majority of tropical legumes are characteristically slow growing compared with the rhizobia of temperate legumes. Generation times in culture are in the range of 3–5 h for the fast growers and 8–10 h for the slow growers. Also, the tropical rhizobia generally produce alkali under standard culture conditions, whereas the temperate rhizobia usually produce an acid reaction. So distinct are the cultural characteristics of these two types of rhizobia that a new genus, *Bradyrhizobium*, has been described for the slow-growing rhizobia. The strains of *Rhizobium* isolated from leucaena are fast growing and neutral, or mildly acid-producing, in their pH reaction. Thus, they are atypical of the rhizobia usually isolated from tropical legumes. Under the old classification, they were placed in the "cowpea miscellany" *Rhizobium* spp. Now, they have been separated from this miscellany, and their correct designation is *Rhizobium loti*.

Leucaena rhizobia can nodulate legumes of other genera more commonly nodulated by the slow-growing rhizobia and usually result in effective, nitrogen-fixing symbioses. But the converse does not occur. Leucaena is specific in its rhizobial requirements, under the categories advocated by Date and Halliday (1980). Leucaena was not nodulated in a field trial in Australia where 18 of 24 other species of legumes were nodulated by indigenous rhizobia in the soil. In the eastern plains of Colombia, which have an array of native legumes nodulated by indigenous strains of rhizobia, leucaena that is sown without inoculation fails to nodulate.

Trinnick (1980) has described the ability of leucaena rhizobia to cross-inoculate with some of the few other tropical legumes that have fast-growing rhizobia (*Mimosa invisa*, *M. pudica*, *Acacia farnesiana*, and *Sesbania grandiflora*) and even with an unusual isolate from *Lablab purpureus* that was fast growing. In our own lab, leucaena nodulated with a fast-growing rhizobial isolate from *Calliandra calothyrsus*.

The cross-inoculation capabilities of the leucaena rhizobia are evident from a study with a mixed inoculant containing three fast-growing rhizobia originally from leucaena and three slow-growing rhizobia isolated from different tropical legumes (Table 1). As specific antisera had been developed for each strain, and each strain was serologically distinct from each of the others, it was possible to determine which strains occupied nodules on 14 species of leguminous trees after inoculation with the six-strain mixture. The infection range of the

Table 1. Presence (+) or absence (−) of each of six strains of *Rhizobium* in the nodules of field-grown leguminous trees inoculated with all six strains at planting (J. Halliday and P.L. Nakao, unpublished).[a]

	Rhizobium					
	Fast growers			Slow growers		
Tree species	TAL 1145	TAL 82	CB 81	CB 756	CB 1024	CIAT 71
Acacia auriculiformis	−	−	−	−	−	+
A. mearnsii	+	−	−	+	−	+
Albizia falcataria	−	−	−	+	−	+
A. procera	−	−	−	+	−	+
Calliandra calothyrsus	+	−	−	−	−	−
Enterolobium cyclocarpum	−	−	−	+	−	+
Erythrina poeppigiana	−	−	−	−	−	+
Glyricidia sepium	+	−	−	−	−	−
Leucaena diversifolia	+	−	−	−	−	−
L. leucocephala	+	−	−	−	−	−
Mimosa scabrella	+	−	−	−	−	−
Sesbania grandiflora	+	−	−	−	−	−

[a] No stand was produced by *Acacia mangium*, and no nodulation occurred in *Acrocarpus fraxinifolius* and *Dalbergia sissoo*.

leucaena *Rhizobium* TAL 1145 was considerably greater than that of all the other strains, exhibiting a competitive edge even over the other leucaena rhizobia for formation of nodules.

Nodulation and nitrogen fixation have been reported (Halliday and Nakao 1982) for all 10 of the leucaena species recognized by Brewbaker. However, *L. retusa*, a native of Texas, has not nodulated in Hawaii soils. This finding is especially surprising given the readiness with which other leucaena species nodulate on the same sites.

Bacteriologically controlled plant-infection tests have confirmed that *L. retusa* is not nodulated by the strains of rhizobia normally used for inoculating leucaena (Table 2).

Tests with several different provenances have been performed, ruling out any possibility that the absence of nodulation was a freak occurrence limited to one *L. retusa* genotype (Table 3). Attempts to nodulate *L. retusa* with slow-growing rhizobial strains isolated originally from *Dolichos lablab* (CB 756), *D. bifloris* (CB 1024), and *Stylosanthes guianensis* (CIAT 71) have so far been unsuccessful. Nodules from *L. retusa* in its native environment have been collected and are under investigation in Hawaii. As yet, these have not yielded a single authenticated strain of *Rhizobium*.

The concept of co-evolution of rhizobial strains and their homologous hosts implies that leucaena introduced to new areas would be unlikely to encounter its specific rhizobial

Table 2. Numbers of nodules formed on roots of different leucaena species raised under bacteriologically controlled conditions in growth pouches and inoculated with *Rhizobium* strains TAL 1145, TAL 582, TAL 600 (P. Somasegaran and H.M. Kamel, unpublished).

	Number of root nodules/plant		
Leucaena species	TAL 1145	TAL 582	TAL 600
L. diversifolia	17.50	8.00	22.00
L. lanceolata	21.00	19.75	21.00
L. leucocephala	16.75	13.75	15.75
L. pulverulenta	0.50[a]	1.25[b]	4.50[a]
L. retusa	none	none	none
L. shannoni	10.00	none	5.75

[a] Two of three replicates nodulated.
[b] Only one of three replicates nodulated.

Table 3. Presence (+) or absence (−) of nodules on four *L. retusa* (K501, K502, K504, K506) accessions when inoculated under bacteriologically controlled conditions with strains of *Rhizobium* (J. Halliday and E. Cuautle-Fabian, unpublished).[a]

Rhizobium strain	Original host	K501	K502	K504	K506
TAL 1145	*L. leucocephala*	−	−	−	−
TAL 582	*L. leucocephala*	−	−	−	−
TAL 583	*L. leucocephala*	−	−	−	−
TAL 309[b]	*Dolichos africanus*	−	−	−	−
TAL 310[b]	*D. bifloris*	−	−	−	−
TAL 658[b]	*Stylosanthes* sp.	−	−	−	−
Nitrogen control		−	−	−	−
Uninoculated control		−	−	−	−

[a] TAL 1145 = CIAT 1967; TAL 582 = CB 81; TAL 583 = NGR8; TAL 309 = CB 756; TAL 310 = CB 1024; TAL 658 = CIAT 710.

[b] Strains TAL 309, 310, and 658 were applied as mixed inoculant.

partner. In practice, however, despite being specific in its *Rhizobium*-strain requirement, leucaena usually encounters compatible soil rhizobia with less difficulty than do other rhizobia-specific legumes, such as soybean.

The documented cases of leucaena's failure to nodulate in geographic areas (e.g., in Australia and Colombia) that are remote from its natural distribution, however, make it prudent to inoculate leucaena seed, at planting, with preselected, elite strains of *Rhizobium*.

Symbiosis in Acid Soils

Leucaena leucocephala is acknowledged to have limited tolerance to acid-soil conditions. Alkali production, which is typical of tropical rhizobia that occur in acid soils, is not a trait of leucaena rhizobia and has been proposed as a reason for leucaena's failure in acid soils. Identification of alkali-producing rhizobia has been regarded as a valid approach to overcoming acid sensitivity in the leucaena–*Rhizobium* symbiosis. However, the thesis has been seriously challenged.

After calling into question the agricultural significance of acid–alkali production (Date and Halliday 1979), one of us (J.H.) conducted selection programs in Colombia and in Hawaii to identify strains of *Rhizobium* with high tolerance to soil-acidity factors. On the premise that acid-tolerant strains need to be capable of multiplying rapidly at low pH if they are to colonize leucaena roots successfully and to cause nodulation in an acid soil, acidified, artificial media were developed to test for this trait (CIAT 1977).

An investigation of the pH-tolerance ranges of leucaena rhizobia isolated from plants growing in soil from three sites of widely differing pH revealed that all of the strains that were recovered from the low-pH (4.5) site possessed the ability to multiply in medium acidified to pH 4.5. None of the isolates from a high-pH (8.5) soil could grow in the acid medium. Data from these investigations (Table 4) emphasize the differing pH-tolerance ranges among rhizobia in naturally occurring populations at sites differing in their soil pH. In these tests, all of the leucaena rhizobia were of the fast-growing type. They were neutral or mildly acid-producing. None of the isolates, including those isolates tolerant to acid pH, produced alkali under the prevailing conditions.

When acid-tolerance screening was combined with the conventional step-wise strain selection (Halliday 1979), strains emerged that were capable of nodulating leucaena abun-

Table 4. Numbers of rhizobial isolates (from nodules on leucaena roots from acid, neutral, and basic soils from the island of Maui, Hawaii) that have the ability to grow on YMA–culture media adjusted to pH 4.5, 7.0, or 8.5 (J. Halliday and K. McGlashin, unpublished).

Collection site	Soil pH	Total isolates	Number of isolates able to grow		
			pH 4.5	pH 7.0	pH 8.5
Kuiaha	4.5	35	35	35	35
Hamakuapoko	7.0	102	79	102	93
Kahului	9.0	39	0	39	39

dantly and effectively in a highly acid (pH 4.1) soil (Llanos Orientales, Colombia). Subsequent testing of the best strain from the Colombian trials (CIAT 1967, now TAL 1145) at an acid-soil site in Hawaii revealed this strain to be more competitive for nodulation than the previously recommended strains CB 81 and NGR8 when inoculated as a mixed inoculant containing equal numbers of each strain.

The strain TAL 1145 also proved highly competitive in comparisons with indigenous rhizobia at the Hawaii site, forming virtually 100% of the nodules tested. At a separate site on the island of Oahu, TAL 1145 was the most competitive of a wide array of introduced strains (H. Maowad, personal communication).

Serological approaches to the study of competition and persistence of leucaena rhizobia are facilitated by the extreme degree of antigenic heterogeneity encountered among the strains in indigenous populations (H. Maowad, personal communication).

As TAL 1145 was neutral in its pH reaction on YMA and as there was no correlation between ability to multiply in acidified media and production of alkali by any of the strains, the relevance of alkali production to success of a strain as an inoculant for acid soils is again disputed.

Nevertheless, successful nodulation was not a sufficient condition to render the leucaena productive in the acid-soil locations. Despite the presence of effective nodulation, plants in plots at pH 4.5 remained stunted and yellow, yielding only 6% of the level of dry-matter production measured for neighbouring plots that had been limed to pH 6.0. Thus, it appears that leucaena rhizobia are able to multiply at a pH in which leucaena itself cannot grow. Leucaena's intolerance of soil acidity can be attributed to the leucaena-plant genome rather than to its rhizobial partner, which has been shown to be acid competent.

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Rhizobia and Nitrogen-Fixing Trees in Singapore

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Leguminous trees in Singapore, especially the common ones, are delineated. Their nodulation status is listed, and their uses are discussed. Data on the growth performance, sugar utilization, and antibiotic reactions of the rhizobia isolates from these tree legumes are also presented.

Les arbres de Singapour de la famille des légumineuses, en particulier les plus communs, sont décrits. On énumère leurs caractéristiques relatives à la formation de nodosités, ainsi que leurs fonctions. On trouvera également des informations sur leur mode de développement, l'utilisation du sucre et les réactions antibiotiques des isolats de rhizobium provenant de ces arbres légumineux.

Se presenta un esbozo de los árboles leguminosos en Singapur, especialmente de los comunes. Se hace un recuento de su estado de nodulación y se discuten sus usos. Se presenta además información sobre crecimiento, utilización del azúcar y reacciones antibióticas de los aislamientos de rizobia a partir de estos árboles leguminosos.

Trees of the legume family are abundant in Singapore. Some are native to the country, but even the introduced species have become successfully established. Tree legumes grow wild in the forests (primary forest at Bukit Timah, secondary forests scattered over the island) and planted as roadside trees and ornamentals in parks and gardens. One species, in particular, has become prominent in Singapore's roadside landscape; this is the Angsana tree *Pterocarpus indicus*, locally referred to as an "instant tree."

Not all leguminous tree species in Singapore possess root nodules (Table 1). In fact, nodules are not always found in mature trees of species whose seedlings have nodules (Lim and Ng 1977), and there are other factors as well that are not well understood (Norris 1956; Lim and Burton 1982). In general, species of Caesalpinioideae nodulate sparsely or not at all, whereas members of Mimosoideae and Papilionoideae are more abundantly nodulated (Allen and Allen 1961; Grobbelaar and Clarke 1974), the degree of nodulation, however, varying considerably.

Nitrogen Fixation

It is assumed that, where nodules are present and appear pinkish, they are actively fixing nitrogen. Direct measurements of nitrogen fixation by such trees have not yet been experimentally obtained, although techniques, such as estimation of ureides (Herridge 1982) in the xylem sap of such trees, are being developed and may provide more direct data on the nitrogen fixed.

Rhizobia Studies

Some of the isolates obtained from nodules of tree legumes were examined for their growth performance and reactions. Many of the isolates have been found to be fast growing (Table 2); all are able to utilize the hexose sugars, with the majority giving an acidic reaction. The isolates are comparatively less able to use two of the pentoses, arabinose, and xylose (Table 3). Most are resistant to penicillin G; less resistant to streptomycin, erythromycin, and chloramphenicol; and relatively susceptible to tetracycline (Table 3).

These studies, though limited, show that tropical rhizobia, at least many of those isolated from trees in Singapore, are not slow-growing, which was thought to be a characteristic of all tropical legumes (Norris 1956). Other studies in the tropics have confirmed the existence of fast-growing rhizobia, which may even be as common as slow-growing ones (Lim and Ng 1977, 1981; Lim 1979). Reactions of the rhizobia on sugars and antibiotics in my studies were consistent with observations made by workers elsewhere (Graham 1963, 1964, 1976; Elkan 1971).

Uses

In Singapore, tree legumes are primarily used for landscape and aesthetic purposes, as shade trees, and ornamental plants. Quick-growing species are favoured for roadside

Table 1. Leguminous trees found in Singapore, with and without nodules.

Species	Origin and use	Degree of nodulation[a]
Subfamily Caesalpinioideae		
Amherstia nobilis	Introduced, reddish-brown roots, gardens, roadsides, and parks	–[b]
Baikiaea insignis	Introduced, gardens and parks	–
Bauhinia bidentata	Indigenous, ornamental, gardens and parks	–
B. purpurea	Introduced, ornamental, parks	–
B. reticulata	Introduced, ornamental, gardens and parks	–
B. tomentosa	Introduced, ornamental, gardens and parks	–
Brownea ariza	Introduced, ornamental, gardens and parks	+
B. capitella	Introduced, ornamental, gardens and parks	–
B. coccinea	Introduced, ornamental, gardens and parks	–
B. crawfordii	Introduced, ornamental, gardens and parks	–
B. grandiceps	Introduced, ornamental, gardens and parks	–
Caesalpinia coriaria	Introduced, ornamental, gardens and parks	–
C. pulcherrima	Introduced, ornamental, gardens and parks	–
Cassia alata	Introduced, ornamental, gardens and parks	–
C. biflora	Introduced, ornamental, gardens and parks	–
C. fistula	Introduced, roadsides, gardens, and parks	–
C. grandis	Introduced (?), roadsides, gardens, and parks	–[c]
C. multijuga	Introduced, gardens and parks	–
C. nodosa	Introduced, gardens and parks	–
C. siamea	Introduced, roadsides, gardens, and parks	–
C. tora	Introduced, ornamental, gardens, parks, and roadsides	+
Delonix regia	Introduced, roadsides and parks	+
Haematoxylon campechianum	Introduced, parks	–
Intsia bijuga	Indigenous, forests	–[b]
Maniltoa grandiflora	Introduced, reddish-brown roots, parks	+ +
Peltophorum africanum	Introduced, roadsides, gardens, and parks	–
P. pterocarpum	Indigenous, reddish-brown roots, roadsides, gardens, and parks	–
Saraca declinata	Introduced, parks	+
S. indica	Indigenous, parks	–
S. thaipingensis	Indigenous, parks	–
Schizophyllum parahybum	Introduced, dark-brown roots	–
Tamarindus indica	Introduced, roadsides and gardens	–
Subfamily Mimosoideae		
Acacia auriculiformis	Introduced, quick growing for shade and roadsides	+ + +
A. bolosericea	Introduced, parks	–[b]
A. farnesiana	Introduced, parks	–[b]
Adenanthera bicolor	Indigenous, roadsides, gardens, parks and forests	–
A. pavonina	Indigenous, roadsides and forests	+
Albizia falcataria	Introduced, roots shallow, branches brittle, gardens and roadsides	+
A. kalkora	Introduced, parks	–
A. odoratissima	Introduced, parks	–[b]
Calliandra emarginata	Introduced, gardens and parks	–
C. inaequilatera	Introduced, ornamental, gardens	+ + +
C. surinamensis	Introduced, ornamental, gardens	+ +
Leucaena leucocephala	Introduced, wild	+ + +
Parkia javanica	Introduced, roadsides and gardens	+
P. speciosa	Indigenous, roadsides and gardens	+

(continued)

Table 1. Concluded

Species	Origin and use	Degree of nodulation[a]
Piptadenia colubrina (now named *Anadenanthera colubrina*)	Introduced, reddish-brown roots, roadsides and parks	–
Pithecellobium jiringa	Indigenous, roadsides, gardens, and forests	–
Samanea saman	Introduced, roadsides, gardens, and parks	+ + +
Subfamily Papilionoideae		
Andira inermis	Introduced, gardens and parks	+
Baphia nitida	Introduced, hedges and fences	+ +
Castanospermum australe	Introduced, ornamental, parks	–
Dalbergia oliveri	Introduced, gardens and parks	–
Erythrina corallodendron	Introduced, roadsides	+
E. glauca	Introduced, gardens and parks	+ +
E. orientalis	Indigenous, gardens and parks	+
Gliricidia sepium	Introduced, gardens and parks	–[b]
Lourea vespertilionsis	Introduced, parks	+ + +
Millettia atropurpurea	Indigenous, gardens and parks	–
Pongamia pinnata	Introduced, seashores	–[b]
Pterocarpus echinatus	Introduced, parks	+
P. indicus	Indigenous, roadsides, "instant trees"	+ + +
P. vidalianus	Introduced, parks	+ +
Sesbania grandiflora	Introduced, gardens, leaves and flowering shoots used as vegetables	+ + +
Subfamily Swartzioidea		
Swartzia pinnata	Introduced, parks	–[b]

[a] – = no nodulation; + = sparse nodulation; + + = moderate nodulation; and + + + = abundant nodulation.
[b] Nodulation reported in the literature.
[c] Conflicting reports of nodulation in the literature.

Table 2. Species from which fast-, slow-, and very slow-growing rhizobia were isolated at 29°C.

Subfamily	Fast growing (≤5 days)	Slow growing (7–10 days)	Very slow growing (≥12 days)
Caesalpinioideae	*B. ariza* *C. tora* *M. grandiflora*	*D. regia*	*S. declinata*
Mimosoideae	*A. pavonina* *A. falcataria* *C. surinamensis* *L. leucocephala* *P. javanica*	*A. auriculiformis* *P. speciosa*	*C. inaequilatera* *S. saman*
Papilionoideae	*A. inermis* *B. nitida* *E. corallodendron* *E. glauca* *L. vespertilionsis* *P. vidalianum* *S. grandiflora*	*E. orientalis* *P. indicus*	*P. echinatus*

plantings and, for this reason, *P. indicus* (Angsana), the "instant trees," are predominantly used. Previously, *Acacia auriculiformis* was also planted but has lost popularity because of the large amounts of leaf litter it produces and the inability of other species to become established in its shade. Small legume trees with showy inflorescences are much favoured in gardens and parks. These include several species of *Bauhinia*, *Brownea*, *Caesal-*

Table 3. Rhizobia utilization of nine carbohydrates and reaction to five antibiotics.[a]

	Carbohydrates									Antibiotics				
Host isolations	Arabinose	Galactose	Glucose	Lactose	Maltose	Mannose	Salicin	Sucrose	Xylose	Chloramphenicol (10 μg)	Erythromycin (10 μg)	Penicillin G (1.5 units)	Streptomycin (10 μg)	Tetracycline (10 μg)
Caesalpinioideae														
B. ariza	+	+	+	+	+	+	+	+	+	+	+	−	+	+
C. tora	+	+	+	+	+	+	+	+	−	+	+	−	+	+
M. grandiflora	+	+	+	+	+	+	+	+	+	+	+	+	+	+
S. declinata	−	+	+	++	+	+	+	+	−	−	−	−	−	−
Mimosoideae														
C. inaequilatera	+	+	+	+	+	+	+	+	−	−	−	−	−	−
P. javanica	+	+	+	++	+	+	+	+	+	−	−	−	−	−
P. speciosa	+	+	+	++	+	+	+	+	+	−	−	−	−	−
S. saman	−	+	+	+	+	+	+	+	−	+	+	−	−	+
Papilionoideae														
B. nitida	+	+	+	+	+	+	+	+	+	−	−	−	−	+
E. corallodendron	+	+	+	+	+	+	+	+	+	−	−	−	−	−
E. glauca	+	+	+	+	+	+	+	+	+	−	+	−	−	+
E. orientalis	+	+	+	+	+	+	+	+	+	+	+	−	−	+
L. vespertilionsis	+	+	+	+	+	+	+	+	+	+	+	−	+	+
P. echinatus	+	+	+	+	+	+	+	+	+	−	−	−	−	+
P. indicus	+	+	+	+	+	+	+	+	−	−	−	−	−	+
P. vidalianus	+	+	+	+	+	+	+	+	+	+	−	−	−	+

[a] For the carbohydrates and antibiotics, respectively: + = acidic reaction when combined with sugar, susceptible to antibiotic; ++ = alkaline reaction when combined with sugar (not included in columns of antibiotics); − = no reaction with sugar, resistant to antibiotic.

pinia, *Calliandra*, and *Cassia*. For hedges, fences, and screens against noise, *Baphia nitida* is increasingly being planted. *Sesbania grandiflora* is fairly common in the more rural parts of Singapore, and two cultivars, one with white flowers the other with red flowers, are generally cultivated. The leaves and flowering young shoots are used as vegetables.

The potential for introducing new species of legumes into Singapore, especially along roadsides and as hedges, is great. Another area where tree legumes may be used to advantage is in coastal reclamation on the island, where appropriate species may help to stabilize the sandy soils and help pave the way for successful establishment of other plant species.

Conclusions

In a land-scarce country such as Singapore, production of tree legumes on a massive scale is not feasible nor desirable. Nor is the cultivation of tree legumes for forage, fuel, and pasture development practicable. Legumes, however, could be more widely used than at present, and new species could be introduced and planted along seashores where the environment is often hostile to other species. For instance, *Prosopis pallida* and *Acacia koa* could be grown along the coast and on reclaimed lands. Judicious plantings of leucaena could also be tried, especially in erosion-control attempts in some parts of Singapore. In the same way, species of *Calliandra* may be of value.

However, the main use for leguminous trees in Singapore is as ornamental plants and shade trees. They will be valuable not only in improving the environment but also in contributing toward land and soil reclamation and erosion control.

Discussion Summary

Many of the leucaena species are cross-compatible — a trait that expands the potential for genetic advance in disease resistance, yield, and site adaptability. In interspecific crosses involving *L. leucocephala*, a promising technique is to identify 104-chromosome individuals from the F_2 generation and backcross to the *L. leucocephala* parent or cross to another *L. leucocephala* line. The economic results from breeding for traits, such as yield increase or broad pest resistance, are likely to come from crosses that are not homozygous and that will, therefore, segregate in succeeding generations of seed. This effect has been demonstrated by *L. leucocephala* in the forage variety Cunningham, which has been found to be unstable and segregating in Hawaii. For this reason, seed from crosses, particularly interspecific crosses, should be obtained from seed dealers and not from growers.

At present, large amounts of seed are being sold internationally, and the emergence of hybrid and composite seed in the international market will provide new opportunities for seed dealers. Two new approaches to seed production are envisaged for the future. The first involves interplanting a self-incompatible species (e.g., *L. diversifolia*) with *L. leucocephala* and harvesting seed from the self-incompatible parent. Another method involves the marketing of carefully mixed multiline seed. Studies in Taiwan and Hawaii have demonstrated that the giant varieties (K8, K28, K29, K67, etc.) all have similar wood-production traits; therefore, mixing the lines in a standard proportion would produce trees with average growth rates and would incorporate some protection against epiphytotics. One obstacle to such mixes at present is the use of more than one designation for a single variety. Thus, efforts will have to be made to standardize nomenclature (based perhaps, on the Hawaiian K nomenclature) — a task that the Nitrogen Fixing Tree Association (NFTA) could well perform.

Interspecific crosses provide great promise for the production of leucaena that can survive well on acid soils. The plant grows poorly — if at all — on acidic soils with high aluminum saturation because, at low pH, the calcium in the soil complexes with the aluminum and is unavailable to the leucaena. Acid-tolerant leucaena varieties are those that can utilize the calcium from the complexes. Such varieties have been selected in pot tests in Colombia, through crosses between *L. leucocephala* and *L. diversifolia*.

Leucaena rarely nodulates in acid soils, even when inoculated with acid-tolerant rhizobial strains. The mode of infection is unknown and is probably a function of plant nutrition. A Ca-starved plant may simply be unable to provide sufficient carbohydrate to the symbiotic process, or the infection process may be interrupted by aluminum in acid soils. In either case, isolating acid-tolerant strains of rhizobia in the laboratory does not hold much promise for plants in the field.

Forage
Production

Firewood/fodder production system in Thailand: the farmer direct seeded an abandoned sugarcane field, harvesting coppiced stems every 6 months. Leaves are sold to a feed mill, and the stems to a pottery company as fuel.

Agronomic Research in the Development of Leucaena as a Pasture Legume in Australia

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Research has established leucaena's value as a persistent, productive, and nutritious leguminous shrub for the coastal and subcoastal areas of subtropical and tropical Australia; however, difficulties in establishing the plant and fear of its toxic effects on livestock have resulted in poor acceptance by graziers. Research has identified some of the factors involved in the slow establishment. These are an inherently low seedling-growth rate, inability to compete well with weeds, delayed nodulation, and high palatability to native fauna. Plant introduction and plant breeding have resulted in the release of three cultivars — Peru, El Salvador, and Cunningham. Efforts to produce a fertile, low-mimosine, high-yielding cultivar using L. pulverulenta *as the female parent have been unsuccessful. If seed-production technology can be developed, F_1 interspecific hybrids could be produced commercially. A large collection (about 700 accessions) is under study at the CSIRO Davies Laboratory. Lines with yield potential higher than Cunningham have been identified, although site × line interactions have complicated evaluation.*

The complex nature of the toxic effects of leucaena on ruminants has largely been unraveled. There is now hope that biological control of toxicity can be achieved. In the absence of clinical signs of toxicity, good weight gains have been recorded in steers and high levels of milk production in dairy cattle. In southeast Queensland, steers on leucaena pastures gained 50–100% more than those on pastures containing siratro, the best-adapted alternative. Priorities for future research in Australia are discussed.

Des études ont démontré la valeur du Leucaena *comme arbuste légumineux persistant, productif et nutritif pour les régions côtières et avoisinantes de l'Australie tropicale et subtropicale. Cependant, les difficultés d'établissement du végétal et la crainte de ses effets toxiques sur les bestiaux l'ont empêché d'être apprécié à sa juste valeur par les herbagers. Des enquêtes ont permis de préciser certains facteurs responsables de ces réticences. Essentiellement celles-ci ont trait à la lenteur de croissance des jeunes plants, à leur difficulté à se défendre contre les mauvaises herbes, à la formation tardive de nodosités et à leur saveur hautement appréciée de la faune indigène. L'introduction de plants et la sélection dont ils ont fait l'objet ont permis d'obtenir trois cultivars : Peru, El Salvador et Cunningham. La recherche d'un cultivar fertile, à rendement élevé et à faible teneur de mimosine, utilisant* L. pulverulenta *comme parent femelle a été infructueuse. S'il était possible de perfectionner les techniques de production de semences, on pourrait produire commercialement des hybrides interspécifiques F_1. Une collection considérable (environ 700 spécimens) est actuellement à l'étude au laboratoire Davies du CSIRO. On a découvert des lignées dont le potentiel de rendement est supérieur à Cunningham, bien que des interactions de lignée et d'endroit viennent compliquer l'évaluation.*

On a, en grande partie, réussi à éclaircir les complexités entourant les effets toxiques de Leucaena *sur les ruminants et l'on peut aujourd'hui espérer les annihiler par des moyens biologiques, ce qui éliminerait l'un des obstacles majeurs à un usage plus répandu de ce végétal. En l'absence d'indices cliniques de toxicité, on a enregistré de bons gains de poids chez les bouvillons et une production laitière abondante des vaches. Dans le sud-est du Queensland des bouvillons sur pâturages de* Leucaena *ont enregistré des gains pondéraux de 50 à 100 % supérieurs à ceux obtenus de pâturages contenant du siratro, autre plante la mieux adaptée. L'exposé discute des priorités futures de la recherche dans le contexte australien.*

La investigación ha establecido el valor de la leucaena como un arbusto leguminoso persistente, productivo y nutritivo para las áreas costeras y subcosteras de Australia tropical y subtropical. Sin embargo, las dificultades para establecer la planta y el temor a sus efectos tóxicos sobre el ganado han resultado en una baja aceptación. La investigación ha identificado algunos de los factores involucrados en el lento establecimiento. Estos son una tasa baja de crecimiento de plántulas, la incapacidad para competir con las malezas, la tardía nodulación y la alta palatabilidad para la fauna nativa. La introducción y el mejoramiento genético han resultado en la liberación de tres cultivares —Perú, El Salvador y Cunningham. Los esfuerzos para producir un cultivar fértil bajo en mimosina y de alto rendimiento usando L. pulverulenta *como progenitor femenino no han tenido éxito. Si se desarrolla la tecnología*

para la producción de semilla se podrían producir comercialmente híbridos interespecíficos F_1. En el Laboratorio Davies del CSIRO se estudia una gran colección (de unas 700 entradas). Ya se han identificado líneas con potencial de rendimiento superior a la Cunningham, aunque las interacciones lote × línea han complicado la evaluación.

La compleja naturaleza de los efectos tóxicos de la leucaena sobre los rumiantes ha sido despejada en buena parte y ahora existe la esperanza de lograr el control biológico de la toxicidad —lo que eliminaría una de las barreras al uso más amplio de la planta. Cuando no hay signos clínicos de toxicidad, se han registrado buenas ganancias de peso en novillos y altos niveles de producción lechera en este ganado. En el sudeste de Queensland, los novillos alimentados con pasturas de leucaena ganaron de 50 a 100% más que aquellos con pasturas que contenían siratro, la alternativa mejor adaptada. Se discuten las prioridades para la investigación futura en Australia

One type of *Leucaena leucocephala* grows naturally in small areas along the coast of northern Australia from Brisbane (27 28'S) to Darwin (12 27'S) (Hutton and Gray 1959) and, according to Seawright (1963, quoting S.L. Everist, the government botanist), has done so for at least 50 years (now 70 years). It grows best in rainforest areas where significant rain falls during each month of the year. This naturalized leucaena is early flowering, free seeding, and fine leafed, known generally as the Hawaiian or common type and thought to have been introduced as seed from New Guinea and Fiji (Hutton and Gray 1959). Most research work in the country has been done with introductions from overseas rather than with the local, naturalized material. In this paper, we discuss the research during the past 25 years that has contributed to a better understanding of leucaena as a pasture legume and highlight areas where more research is required.

Genetic Resources and Evaluation

Between 1955 and 1967, more than 100 introductions were tested by the CSIRO Division of Tropical Crops and Pastures (then the Division of Tropical Pastures). Most of these introductions were similar to the low-yielding, naturalized type (Gray 1968). Two cultivars were released to the grazing industry, Peru (CPI[1] 18614) and El Salvador (CPI 18623) (Barnard 1972). Both cultivars were higher yielding than the local Hawaiian type, with Peru giving the highest yields (Hutton and Bonner 1960). El Salvador is atypical of the Salvador giant types (Bray 1980) and, as it is less productive than Peru, has been little used in subsequent experiments or on commercial farms.

In 1976, Cunningham, derived from a cross between Peru and a line from Guatemala (CPI 18228), was released (Mackay 1976). It was bred by E.M. Hutton and has significantly outyielded Peru in some situations (Jones 1974; Hutton and Beattie 1976) but not in others (C.G. Blunt and R.J. Jones, unpublished data; D.G. Cooksley, unpublished data;

[1] CPI = Commonwealth plant introduction number.

Table 1. Annual yields (kg/ha) of three leucaena cultivars (edible dry matter[a] or leaves) at three sites in Queensland, Australia.

Site[b] and harvest method[c]	Cultivar[d] Hawaii	Peru	Cunningham	Reference
Samford				
Plucking	1500	12500**	—	Hutton and Bonner 1980
Cutting	—	3600	5480**	R.J. Jones and Cardoso (unpublished)
Lansdown				
Plucking	—	1500	1900*	Hutton and Beattie 1976
Cutting	—	3820	5460**	Hutton and Beattie 1976
South Johnstone				
Cutting[e]	—	9150	10300	Ferraris 1979

[a] Edible dry matter comprises leaves plus young stems < 6 mm in diameter.

[b] Latitude and mean annual rainfall for Samford, Lansdown, and South Johnstone respectively are 27 22 S, 1097 mm; 19 40 S, 862 mm; 17 36 S, 3219 mm.

[c] Plucking is removal of the edible matter from intact stems; cutting is removal of aerial part of plant 15–30 cm above ground.

[d] Significant differences from control. * = $P < 0.05$, ** = $P < 0.01$.

[e] Yield of leaves only.

Ferraris 1979) (Table 1). In general, its performance is similar to Peru, and it has a similar mimosine content, although the xanthophyll concentration in its leaves is much higher (Savory 1979). Cutting management has such a strong influence on the yield of edible dry matter (Table 1) that the relevance of experiments where leucaena is cut low is questionable in relation to production under grazing.

Since 1967, the germ-plasm collection at CSIRO has increased markedly and, at present, comprises *L. trichodes* (3 accessions), *L. macrophylla* (31), *L. lanceolata* (22), *L. retusa* (9), *L. leucocephala* (ca 500), *L. collinsii* (4), *L. diversifolia* (10), *L. pulverulenta* (45), *L. esculenta* (24), and 42 unknown or undetermined accessions. Many of these accessions have been collected since 1977, largely through the efforts of R. Reid during his visit to Mexico.

Within the *L. leucocephala* pool, there are several lines with higher yielding ability than Cunningham, notably CPI 61227 from Mexico and CPI 58396 from Barcelona. Large increases in yield are also possible from crosses derived from *L. pulverulenta* and *L. leucocephala*, although marked site · line interactions complicate evaluation procedures (Bray 1981).

Establishment and Nodulation

The palatability of leucaena seedlings to marsupials, rabbits, and hares, as well as domestic stock, means that pastures must be fenced if the plants are to be established successfully. Leucaena is slow to establish in the field, and seedlings compete poorly with weeds (Cooksley 1974). These characteristics have contributed to the slow acceptance of the species by graziers in Australia. Rapid and uniform germination can be obtained, however, if seeds from ripe pods are scarified. The standard treatment is to immerse the seeds for 2–4 minutes, in water maintained at 80 C, followed by rapid drying (Gray 1962). A more rapid and uniform emergence of seedlings (80% versus 10% after 6 days) was obtained in laboratory studies in which treated seeds were allowed to imbibe water for up to 72 h, or until radicles began to emerge, and then dried (Jones 1970). Beneficial effects in the field were, however, much smaller.

Although seeds are large (52 mg) compared with the seeds of grass weeds such as *Eleusine indica* (0.4 mg), relative weekly growth rate is slow (0.55 g/g) (Egara and Jones 1977). In competition with *E. indica* in the ratio of 1 : 1, yield of leucaena was reduced to 26% of that in pure stands. Individual-plant weight for leucaena grown alone was 0.9 g compared with 3.1 g for *E. indica* after 3 months, and respective heights were 13.7 cm and 35.6 cm (Jones and Aliyu 1976). Subsequent work showed that shoot competition (shading) only accounted for 15% of the yield depression, whereas 85% was caused by root competition (Jones and Egara 1977).

Difficulty in establishment on some soils may also reflect delays (up to 50 days) in nodulation. Even with inoculant levels at 200 times the normal rate, the time to nodulate was only slightly reduced (Bushby 1982). This delayed nodulation means that the plant must compete for nitrogen during this period, and, unless weeds are controlled, either the sowing will fail or establishment will be prolonged.

Unlike some other tropical-pasture legumes, the seedlings of leucaena tolerate shade well (Egara and Jones 1977). Even at 35% relative photosynthetic quantum flux in a glasshouse, relative growth rate of shoots was affected little, and the leaf-area index was increased. Root growth, however, was greatly reduced (Egara and Jones 1977), with a resultant reduction in the plant's ability to compete for nutrients.

Thus, weed control is essential for rapid establishment, and various herbicides and methods of application have been studied. Unfortunately, few studies have been published. Under irrigated conditions in the Ord Valley, northwest Australia, the slow emergence of leucaena enables paraquat to be used to control the faster-emerging weed seedlings. Spraying when the first leucaena seedlings emerge may kill 5% of the leucaena but gives good weed control (C.G. Blunt, personal communication).

No clearcut recommendations for weed control have been developed in Australia, and the variations in soils and rainfall conditions would probably militate against standard treatments. Cultivation to destroy weeds before planting is considered to be the most reliable way of reducing weed competition (D.G. Cooksley, personal communication). Of the preemergent herbicides used, 2,4-D is one of the cheapest and most effective, particularly against dicot weeds (Shaw 1965; Cooksley 1974; Jones 1975). Unfortunately, 2,4-D Trifluralin and Dacthal (DCPA) reduce leucaena growth, and

Dacthal can cause serious taproot damage (Jones and Aliyu 1976).

Use of activated charcoal above the seed alleviates the adverse effects but unexpectedly reduces yields when used alone (Jones and Aliyu 1976). In a field study, a combination of 2,4-D and Dacthal, applied as a preemergent spray over rows protected by activated charcoal (30 kg/ha), gave good weed control and leucaena yields that did not differ significantly from hand-weeded controls (R.J. Jones, unpublished data). However, the application of charcoal in suspension requires special equipment that may limit its use. Varying the type of charcoal used to bind specifically the herbicide formulations offers potential to maximize weed control and minimize toxicity to the leucaena.

In native pastures with low soil reserves of weed seeds, the use of glyphosate (Roundup®) applied in strips effectively removes competition and enables leucaena to establish successfully when drilled into the killed sward (G.H. Malcolmson, personal communication). The method offers promise for establishment of leucaena on steep hillsides without the erosion risks associated with plowing and cultivating and could have economic advantages in other situations. An alternative is the establishment of leucaena in strips along the contour with or without the use of herbicides.

In some experiments, sowing seeds 5 cm deep or deeper greatly reduced emergence of seedlings (Jones 1970), whereas, in experiments on a moist, clay soil, sowing at 6 cm with a combine planter gave good establishment (Cooksley, in press).

Rhizobium Requirements

Rhizobia effective on leucaena are consistently fast-growing, acid-producing strains (Norris 1965), some of which may nodulate *Medicago sativa*, though not effectively (Trinnick 1965). Large differences in effectiveness between isolates have been demonstrated in glasshouse experiments (Norris 1965), but strains effective under these conditions may not always perform well in the field. On a podzolic soil with pH 5.0, the mild acid-producing strain CB 81 nodulated leucaena whether the seed was lime-pelleted or not, whereas the fast-growing, acid-producing strain NGR8 failed to form nodules unless the seed was lime-pelleted (Norris 1973). Even on lime-pelleted seed, the percentage of nodules from NGR8 3 years after sowing was virtually zero and the percentage from CB 81 averaged only 35 (Bushby 1982). Further experiments have confirmed the low survival of NGR8 in acid soils and have shown that native rhizobia gradually replace the applied strains (Bushby 1982). Clearly, better *Rhizobium* strains and more effective methods of inoculation need to be developed if leucaena establishment is to be made more reliable.

Management

Experience in leucaena management in Australia has been documented by Jones and Jones (1979) and Jones et al. (1982). The leucaena is usually established in rows 2 – 4 m apart, fertilized with nutrients deficient in the soil, and grazed leniently and rotationally in the first few years until a good framework and strong root system are established. Grasses are sown or planted later so that competition in the year of establishment is minimal. When fully established, the leucaena pasture is grazed rotationally because the animals often completely defoliate the leucaena at each grazing and can eventually destroy the plants (Jones and Jones 1982). The plants recover well if grazed for 1 – 2 weeks and allowed to rest 4 – 6 weeks. A two-paddock system with 4 weeks of grazing followed by 4 weeks' rest has also been found suitable. It is easier to keep leucaena under control in the subtropics than in the tropics, particularly if the stems are frosted and killed in winter. In the tropics, increased stocking rates, combined with occasional mechanical slashing, may be needed to keep the leucaena within grazing height (1.5 – 2 m) during the summer. Leucaena plants grazed rotationally are usually long-lived, with good stands persisting for more than 20 years without the need for regeneration from seed (Jones and Harrison 1980).

Pastures of leucaena may be used in a rotation system with larger areas of native pasture (Shaw 1968; Anonymous 1981) or as the major feed supply for cattle (Table 2). If the leucaena is used as a supplement, then grazing of these pastures can be varied so that high-quality feed is accumulated for the dry season. A novel approach to using leucaena in conjunction with native pasture involves growing the leucaena as trees and using the lower branches and seedlings under the canopy as the supplemental protein source (Wildin 1980). This system, which was first used with regular mechanical harvesting of seed, needs to be tested under a variety of other conditions before being widely recommended.

Table 2. Animal production from grazed leucaena pastures in Australia.

Pasture[a]	Stocking rate (beast/ha)	Live-weight gain (kg/beast)	Annual (kg/ha)	Reference
Leucaena + setaria	2.0	200[b]	400[b]	Jones 1973
Leucaena + pangola	4.9	118	580	Blunt 1976
Leucaena + pangola	6.2	134	830	Blunt 1976
Leucaena + pangola	7.4	96	710	Blunt 1976
Leucaena + pangola	8.6	56	490	Blunt 1976
Leucaena + pangola	5.6	91	510[c]	Blunt and Jones 1977
Leucaena + pangola	7.4	76	562[d]	Blunt and Jones 1977
Leucaena + rhodes	1.9	171	325	Jones and Jones 1982
Leucaena + rhodes	2.5	125	311	Jones and Jones 1982
Leucaena + setaria	2.0	162[e]	427	Jones and Jones 1979
Native grass (1.2 ha/beast)	0.83	95	79	Anonymous 1981
Native grass + 17% leucaena	0.83	140	116	Anonymous 1981

[a] The leucaena plus pangola pasture was irrigated.
[b] Gain over 215 days.
[c] Gain over 308 days.
[d] Gain over 280 days.
[e] Mean gain over 5 years for yearlong grazers with cv Cunningham.

Often, leucaena pastures require fertilization for high production. At establishment, fertilizer requirements are expected to be similar to those required for pastures of siratro, desmodium, or neonotonia. On acid soils (pH 5.4), lime is required. Maintenance requirements have not been studied but would vary with soil type, rainfall, and intensity of management. Deficiency symptoms are a clue to the need for application of specific nutrients (Gonzales et al. 1980).

Diseases and Pests

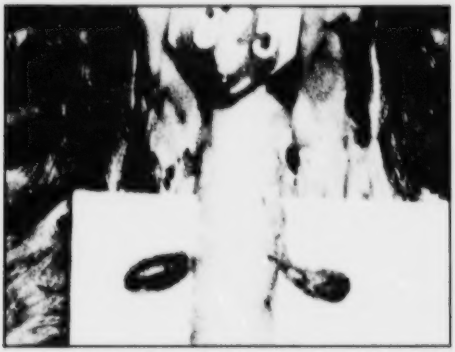
There have been no major disease or pest problems in leucaena to date. Attacks of cutworms and termites at establishment and soft scale (*Cocus longulus*) on mature stems have been encountered but are not regarded as serious. Recently, larvae of the moth *Ithome lassula* have been found attacking the inflorescences and young pods of leucaena in north Queensland (Common and Beattie 1982). Although not a direct problem for the grazier, seed yields could be seriously affected.

Seedlings of leucaena are very susceptible to damping-off when grown in wet conditions and should be treated with fungicides or post-emergence sprays in midsummer in areas where rainfall is heavy.

Toxic Effects

The presence in leucaena of the amino acid mimosine makes it potentially toxic to livestock. Originally, ruminants were thought to be unaffected, but experience in Australia proved otherwise. Hair loss has been observed in cattle grazing leucaena pastures (Hutton and Gray 1959) and in a buffalo calf fed fresh leucaena as part of the diet, although the latter regrew hair when leucaena feeding ceased (Letts 1963). Sheep fed diets of leucaena shed their fleece within 7–14 days (Hegarty et al. 1964) and may die (Reis et al. 1975). Mimosine is a powerful depilatory agent that cannot be degraded after absorption but can be extensively degraded to 3-hydroxy-4(1H) pyridone (DHP) in the rumen if the sheep are gradually conditioned to high levels of leucaena (Hegarty et al. 1964). When pregnant ewes were fed, ad libitum, leucaena during their pregnancy for 30 or 90 days, they failed to maintain weight; produced lightweight, goitrous lambs, devoid of thymus tissue; and had higher neonatal losses than did comparable ewes fed lucerne. No fleece shedding was observed, but the ewes had ulcers in the esophagus (Bindon and Lamond 1966). In a similar experiment (Little and Hamilton 1971), ewes fed leucaena at 1% mimosine content for the last 60 days of pregnancy failed to show the adverse responses noted above. However, elevated protein-bound iodine (PBI) values were recorded in the lambs, and these were not prevented by supplements of iodine to the dams (Little and Hamilton 1971).

In experiments with cows, leucaena did not affect estrous cycle length, conception rate, or gestation length, although some cows experi-



Thyroid glands of goat fed grass — no abnormalities; weight is 2–3 g.

enced mild incoordination and nervous symptoms for a short period during gestation and lost some hair (Hamilton et al. 1971). Calves from cows fed leucaena had lower birth weights than did calves from lucerne-fed controls (19.6 kg versus 25.8 kg), were goitrous, and had elevated PBI levels (Hamilton et al. 1971). Enlarged thyroid glands were also a feature of cattle grazing mixed grass–leucaena pastures and were associated with low serum thyroxine (T_4) levels (Jones et al. 1976). Cumulative effects of leucaena were evidenced by depressed weight gains and development of clinical signs. New animals introduced to the pasture gained 1 kg/day compared with gains of 0–0.2 kg/day for resident animals. In subsequent experiments, a linear relation between serum T_4 levels and live-weight gains of cattle, grazing pangola–leucaena pastures, was established over the range 10–80 nmol/L (Jones and Winter 1982). Since clinical signs of toxicity were not recorded until T_4 levels fell below 30 nmol/L, considerable losses in productivity could be experienced well before any observable signs of toxicity.

Although mineral supplements containing zinc, copper, and iron alleviated the skin lesions and excessive hair losses of steers fed solely on leucaena, neither these nor iodine injections prevented the decline in T_4 levels (Jones et al. 1978). Goitre was clearly not simply caused by iodine deficiency and was unlikely to have been induced by thiocyanate.

In a fruitless search for potential goitrogens in leucaena, it was shown that mimosine was not goitrogenic (Hegarty et al. 1979) but that its degradation product in the rumen, DHP, was a potent goitrogen of the thiouracil type (Hegarty et al. 1979). Inhibition of ^{125}I uptake by the thyroid appeared to occur at the iodine-binding step and not at the iodine-trapping step as with thiocyanate (Hegarty et al. 1979).

Identification of the goitrogen was a major step in creating an understanding of the reaction of ruminants to leucaena feeding. It explained why ruminants in Australia showed leucaena toxicity, even though they were capable of completely degrading mimosine in the rumen. The adverse effects of DHP could not be overcome by iodine supplementation but were reversible. When leucaena was removed from the diet, appetite increased and T_4 levels returned to normal in 4 weeks (Jones et al. 1978). Steers that alternately grazed pangola grass and leucaena–pangola pastures made better gains than those permanently on leucaena pastures (Blunt and Jones 1977). Steers fed diets with 10% or 20% young leucaena shoots showed none of the clinical signs associated with leucaena toxicity after prolonged feeding. At dietary levels of 40%, 80%, and 100%, leucaena depressed serum T_4 and serum T_3 (triiodothyronine) levels, and steers lost weight on the 80% and 100% leucaena diets (Jones 1979).

The depressed appetite of animals on high-leucaena diets is probably associated with levels of DHP in the circulatory system rather than with low thyroxine levels per se as daily administration of thyroxine to maintain normal T_4 levels failed to increase feed intake significantly (Megarrity and Jones, in press). Restricting intake of leucaena would, therefore, be effective in preventing toxicity but would be difficult in grazed pastures.

Thyroid glands of goat fed leucaena for 3 months — enlarged to 16 g.

The toxicity in ruminants fed leucaena in Australia has not been reported in Hawaii where the shrub is naturalized and is grazed by cattle or cut and fed to goats. Absence of such adverse reports prompted a study by one of us (R.J.J.) with goats in Hawaii in 1979. The results showed that goats were not adversely affected even when fed a sole diet of fresh leucaena (Jones 1981). Degradation of both mimosine and DHP occurred when incubated with rumen fluid in vitro. The results were completely different from a similar study in Australia, in which goats fed solely leucaena rapidly became hypothyroid, lost appetite, did not degrade DHP in their rumen, and excreted large quantities of DHP in urine (Jones and Megarrity, in press). From these studies, it was hypothesized that the failure to metabolize DHP in Australia reflected an absence of rumen microorganisms capable of degrading DHP (Jones 1981; Jones and Megarrity, in press). Further support for this hypothesis has recently been obtained by researchers transferring rumen fluid from an Indonesian goat known to be degrading DHP to Australian goats fed on Australian-grown leucaena. After only one infusion, the recipients acquired the ability to degrade DHP (Jones and Lowry, in preparation). Mixed cultures of the DHP-degrading bacteria have been grown successfully in vitro with anaerobic techniques and have been introduced from Hawaii into Australia where they will be used under strict quarantine to introduce the DHP-degrading capacity into Australian goats and cattle (R.J. Jones and R.G. Megarrity, unpublished data). If successful, these experiments will provide a biological solution to the leucaena-toxicity problem in Australia and so remove one of the hindrances to wider use of leucaena in pastures.

Problems similar to those described in Australia have been reported for cattle fed high levels of leucaena in Africa (Compere 1959; Vohradsky 1972) and in Papua New Guinea (Holmes 1981). The presence or absence of DHP-degrading microorganisms in any area can readily be confirmed by urinalysis for DHP (Megarrity 1981) in animals on diets containing more than 50% leucaena on a dry-matter basis.

Feeding Value and Animal Production

The nutritive value of leucaena has been reviewed elsewhere in some detail (Jones 1979). It is sufficient to note that, although sodium is consistently low in the plant and iodine may be low, the mineral composition of well-grown leucaena is usually adequate for productive livestock. In areas where pastures are a mixture of leucaena and low-sodium grasses, such as *Panicum*, or where leucaena forms a large part of the diet, iodized salt may be needed to prevent deficiencies.

In Australia, studies to measure intake and digestibility of leucaena have been plagued by toxicity problems in the animals. Until the problem is solved, it will be impossible to get meaningful figures on the potential nutritive value of the material.

Studies that compare the feeding values of leucaena with other shrub species have been few, although Bamualim et al. (1980), using the nylon-bag technique, found that the digestibility values for leucaena cultivars and introductions were generally higher than those from a number of other shrubs, including *Acacia*, *Desmanthus*, *Albizia*, *Bauhinia*, *Calliandra*, *Cajanus*, and *Lysiloma*. Digestibility of the leaves varied little with season — a finding that contrasts with the rapid decline in digestibility of native grasses during the dry season (Bamualim et al. 1982).

Data on animal production from grazed pastures are also relatively few. Under irrigated conditions in northwest Australia, however, grazing experiments have shown that cattle on the irrigated leucaena–pangola pastures are invariably hypothyroid, and those on the leucaena–rhodes and leucaena–setaria consistently have an enlarged thyroid gland within 1 year (Jones et al. 1976; Jones and Jones 1979). Milk yields for 9 months from cows on leucaena and green panicum (4.78 cows/ha) were 1316 kg/cow or 6.3 t/ha (Stobbs 1972).

In a comparative study in northern Australia, a leucaena–*Cynodon dactylon* pasture gave higher live-weight gains than did adjacent pastures of Townsville stylo (TS)–*P. maximum* var *trichoglume* or TS–*Cenchrus ciliaris*, which contained 35% TS (Falvey 1976). Heifers rotationally grazing leucaena pasture in conjunction with a TS–grass pasture gained 16 kg more during the dry season than did those grazing the TS pasture only — a response associated with low-legume content in the base pasture (Falvey 1976).

There are no other direct comparisons of leucaena pastures with other legume-based pastures. However, maximum annual live-weight gains (1330 kg/ha) from irrigated,

nitrogen-fertilized (310 kg N) pangola grass in the Ord Valley (Blunt 1978) were higher than those from leucaena–pangola (830 kg/ha) (Blunt 1976). At Samford, southeast Queensland, annual live-weight gains (311 kg/ha) on leucaena–setaria were higher than those from siratro–setaria pastures (200 kg/ha) under similar conditions (Jones and Jones 1982). Leucaena toxicity has not been as severe or as consistent in southeast Queensland as in the more tropical areas of Townsville and Kununurra, in the Ord Valley. At the warmer sites, a marked improvement in animal production could be expected if the toxicity problem could be overcome.

Breeding performance of beef cattle on leucaena pastures has also varied. At Samford, heifers solely grazing leucaena–grass pastures showed a 78% calving compared with 89% calving for a farm herd grazing other pastures (Jones and Jones 1981). All cows grazing leucaena pastures at Kununurra produced goitrous calves in the wet season, most of which died within 3 days of birth (Jones et al. 1976). These results may be compared with those in New Guinea where heifers had low conception rates on leucaena pastures despite good body condition and some had cataracts (Holmes 1981).

In contrast, supplementary grazing of leucaena in conjunction with native pastures proved beneficial near Gayndah, southeast Queensland: the calving rate of cows that had calved the previous year and had access to leucaena (17% of total area) was 70% compared with 50% from cows at the same stocking rate without leucaena (Anonymous 1981).

Priorities in Research

The problems for the future are largely those that have been recognized for a long time (Jones 1979) but are now better understood. Efforts should be to:

- Explore the existing germ-plasm collection to describe the variation encountered, to define the areas of climatic and edaphic adaptability, to identify superior introductions capable of higher yields, of wider adaptability, and with better agronomic or nutritional attributes than the existing cultivars. So far, all Australian work has been on *L. leucocephala*, but, with testing of the accessions available at CSIRO, major advances can be expected.
- Develop reliable establishment strategies, through the selection of leucaena germ plasm or *Rhizobium* for rapid nodulation to reduce the period during which the seedling behaves as a nonlegume and to develop inoculation techniques to aid multiplication of the *Rhizobium* in the soil and rhizosphere (Bushby 1982). In addition, herbicides to control or eliminate competition from weeds will need to be combined with suitable sowing equipment to foster rapid establishment, reduce costs, and prevent erosion.
- Eliminate the toxicity problem. Thus far, it has not been possible to combine vigour with low-mimosine concentration through plant breeding. Although F_1 hybrids between *L. pulverulenta* and *L. leucocephala* show promise, the use of rumen microorganisms to degrade the goitrogen DHP in the rumen offers hope that a biological solution will be found (Jones and Megarrity, in press). The problems in introducing the DHP-degrading microbes into commercial herds need to be explored, and suitable techniques developed.
- Define the production systems in which leucaena will make the greatest contribution. Rarely will leucaena occupy a large proportion of a grazing property; producers need to know in what situations it will grow best and in what part of the cattle-production system it will make the greatest contribution, e.g., fattening steers, supplementing breeders at mating, or providing pasture for weaners.
- Identify the soil characteristics that result in poor production. On the basis of these results, the area of adaptability in northern Australia could be better defined.
- Determine the fertilizer requirements for establishment and maintenance of grazed leucaena pastures and develop reliable techniques for predicting nutrient requirements.
- Measure the feeding value of leucaena. In particular, the role of tannin in the natural protection of protein through the rumen and its subsequent fate in the digestive tract need clarification.
- Develop seed-production and management systems that enable seed to be sold at a more reasonable price than the current AU$ 20+/kg, which is high enough to discourage some potential users. The possibilities of mechanical seed harvesting also should be investigated.

Detoxification of Leucaena by Enzymic or Microbial Processes

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New information about the effects of leucaena in the diets of livestock has become available so rapidly that many researchers are still unaware of the differences in toxicity brought about by mimosine and its degradation product 3-hydroxy-4(1H)pyridone (DHP). Although mimosine is directly toxic, DHP is only indirectly so through its goitrogenic action. Thus, animals that can break down the mimosine to DHP can tolerate higher dietary levels of leucaena than can other animals, and animals that can degrade DHP even further can tolerate higher levels yet, perhaps even diets that are solely leucaena. The enzyme necessary to convert mimosine to DHP is contained in some (but not all) of the leucaena cells that harbour the mimosine. Conversion occurs when the enzyme comes in contact with the substrate, for example, through maceration. The enzyme becomes inactive at pH levels lower than 4, when heated suddenly to temperatures higher than 70°C, and when dried. These findings have enormous implications for past and future research. For instance, animals grazing leucaena pastures would initiate conversion of mimosine to DHP by chewing the leaves. The conversion would continue until virtually complete in ruminants but would be halted in monogastric animals by the acid in the stomach. Commercial leaf meal that has been sun dried during clear conditions or rapidly air dried would have the mimosine virtually intact, but the enzyme would be denatured. In contrast, leaf meal from leucaena that had deteriorated, for example in a plastic bag in the sun or lying in a heap during wet conditions, would have much of its mimosine converted to DHP. The conversions that take place under specific circumstances could explain many of the conflicting reports about toxicity from leucaena fed to both ruminants and nonruminants.

Une nouvelle documentation concernant le rôle du Leucaena dans l'alimentation des bestiaux s'est à ce point développée que beaucoup de chercheurs n'ont pas encore pris connaissance des différences dans la toxicité imputée à la mimosine et à son produit de dégradation 3-hydroxy-4 [1H] pyridone (DHP). Bien que la mimosine soit directement toxique, le DHP ne l'est qu'indirectement par ses propriétés goitrogènes. C'est pourquoi les animaux capables de décomposer la mimosine en DHP peuvent tolérer dans leur régime des quantités plus considérables de Leucaena que d'autres animaux, et ceux qui peuvent décomposer DHP plus encore, en toléreront des quantités encore supérieures et s'accommoderont même d'un régime entièrement à base de Leucaena. L'enzyme nécessaire pour convertir la mimosine en DHP se retrouve dans certaines des cellules (mais non dans toutes) de Leucaena qui contiennent la mimosine. La conversion s'effectue lorsque cet enzyme entre en contact avec le substrat, par exemple, par la macération. L'enzyme devient inactif devant un pH inférieur à 4, lorsqu'on le chauffe brusquement à plus de 70 °C, et à l'état sec. Ces constatations offrent d'immenses implications pour les études passées et à venir. Par exemple, les animaux paissant dans des pâturages de Leucaena commenceraient cette conversion de la mimosine en DHP en mâchant les feuilles. Le processus se poursuivrait jusqu'à son parachèvement presque intégral chez les ruminants, mais serait interrompu par les acides stomacaux chez les animaux monogastriques. La farine commerciale de feuilles séchées au soleil, ou rapidement à l'air, laisserait la mimosine à peu près intacte, mais l'enzyme serait dénaturé. Par contre, la farine de feuilles de Leucaena avariée pour être restée exposée au soleil dans des sacs en plastique, ou en tas dans des conditions humides, verrait une grosse partie de sa mimosine convertie en DHP. Ces conversions se produisant dans des circonstances bien particulières pourraient expliquer certains rapports contradictoires concernant la toxicité de Leucaena dans les régimes des ruminants et des monogastriques.

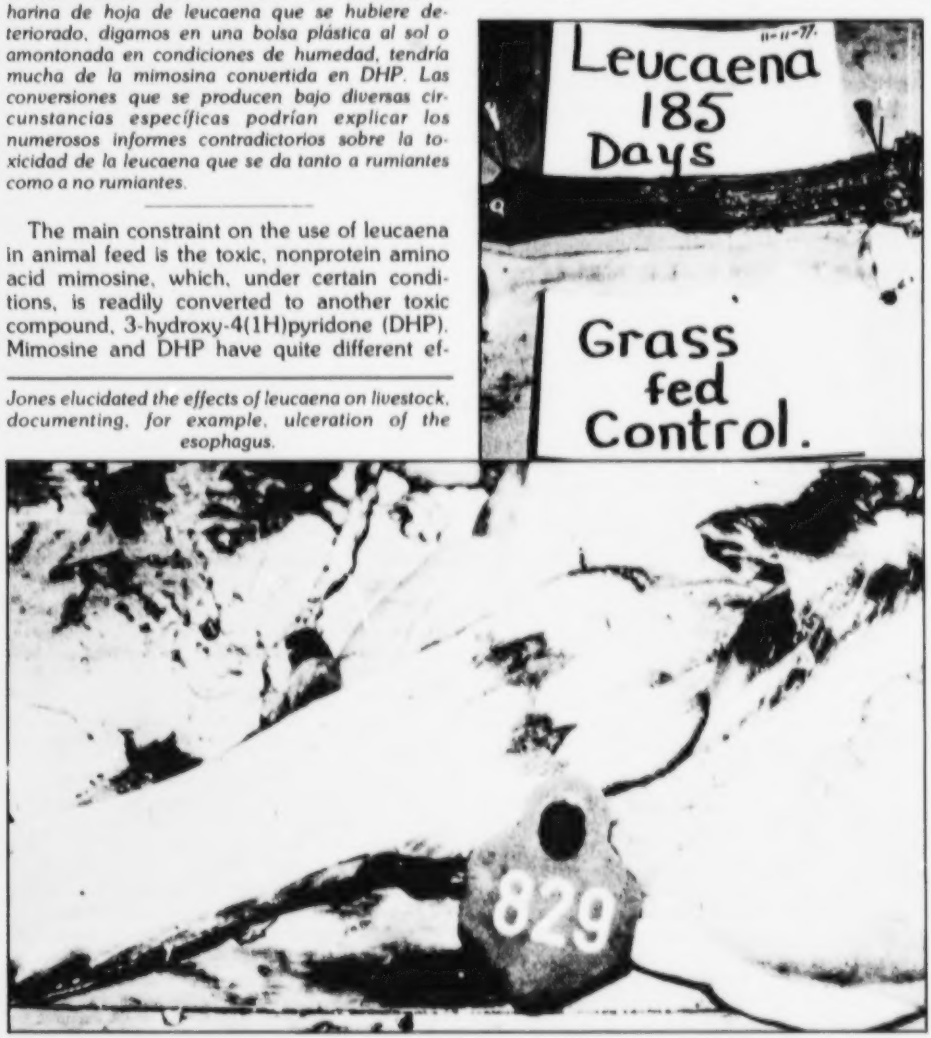
La nueva información sobre efectos de la leucaena en las dietas del ganado ha aparecido tan rápidamente que muchos investigadores aún desconocen las diferencias en toxicidad producidas por la mimosina y su producto de degradación 3-hydroxy-4(1H)pyridone (DHP). Aunque la mimosina es directamente tóxica, el DHP lo es solo indirectamente mediante su acción bociogénica. Así, los animales que pueden descomponer la mimosina en DHP pueden tolerar niveles más altos de leucaena en la dieta que otros animales, y los animales que pueden degradar aún más el DHP pueden tolerar también mayores niveles, quizás dietas solamente de leucaena. La enzima necesaria para convertir la mimosina en DHP se encuentra en algunas (no todas) de las células de leucaena que contienen la mimosina. La conversión ocurre cuando la enzima entra en contacto con el sustrato, por ejemplo, mediante maceración. La enzima se

toma inactiva a niveles de pH menores de 4, cuando se calienta repentinamente a temperaturas por encima de 70°C o cuando se seca. Estos hallazgos tienen serias implicaciones sobre la investigación pasada y futura. Por ejemplo, los animales que pastan leucaena iniciarían la conversión de mimosina en DHP mediante la masticación de las hojas. La conversión continuaría hasta ser virtualmente completa en rumiantes, pero sería detenida en los monogástricos por el ácido del estómago. La harina de hoja comercial que ha sido secada al sol en condiciones claras o secada rápidamente al aire tendría la mimosina prácticamente intacta, pero la enzima estaría desnaturalizada. En contraste, la harina de hoja de leucaena que se hubiere deteriorado, digamos en una bolsa plástica al sol o amontonada en condiciones de humedad, tendría mucha de la mimosina convertida en DHP. Las conversiones que se producen bajo diversas circunstancias específicas podrían explicar los numerosos informes contradictorios sobre la toxicidad de la leucaena que se da tanto a rumiantes como a no rumiantes.

The main constraint on the use of leucaena in animal feed is the toxic, nonprotein amino acid mimosine, which, under certain conditions, is readily converted to another toxic compound, 3-hydroxy-4(1H)pyridone (DHP). Mimosine and DHP have quite different effects, the knowledge of which is developing quite fast and being disseminated in a rather uneven way. For this reason, I think it useful to summarize research on the toxic properties of leucaena in terms of three periods: up to 1976, 1976–79, 1979 to date.

Developments to Date

In 1937, there were classic studies on the isolation and structural determination of mimosine and, later, on its cytotoxic and depilatory effects. After an early diversion



Jones elucidated the effects of leucaena on livestock, documenting, for example, ulceration of the esophagus.

concerning selenium, virtually all the adverse effects of leucaena were attributed to mimosine. The value of the crop in particular animal-production systems was recognized; however, large differences in response to leucaena diets emerged. Ruminants were observed to convert mimosine to DHP, which was regarded as essentially nontoxic. Nevertheless, toxicity was still a problem. This period is well covered in the National Academy of Sciences (NAS 1977) book on leucaena, and, because of the publication's wide distribution, most workers with leucaena are aware of the basic findings up to 1976.

The separate toxic effects of mimosine and DHP became apparent, between 1976 and 1979, and there were definitive studies on the goitrogenic effects of DHP. These suggested that, when leucaena is fed to ruminants at high levels, there is an intractable problem caused by the antithyroid effects of DHP. Breeding plants with low mimosine content and limiting the supply of leucaena in the animals' diets were seen as the only ways to avoid toxicity. Despite the rather daunting chronic toxicity revealed in some studies, the nutritive value of leucaena was recognized, and, with proper management, leucaena could contribute very usefully to increased animal production. The work on the goitrogenic activity of DHP is well published but scattered. The advances were gathered together by R.J. Jones (1979). Jones' article was timely and was directed to the right people. It is still making an impact. A surprising number of scientists interested in leucaena are not yet aware of the different toxic properties of mimosine and DHP.

From 1979 to the present has been a period of rapid and stimulating change. No sooner did the definitive picture seem to be emerging (defined largely by Jones and Hegarty) than the foundations were shaken once again. Having observed utilization of leucaena in different countries, Jones became convinced that there were qualitative differences — that the apparent absence of chronic effects in some areas was a reflection not of low-mimosine leucaena, low intake, or poor observation of animals but of different metabolism of the feed. In 1979, in Hawaii, he monitored goats in a village system and found that DHP was being rapidly broken down and that complete detoxification of leucaena apparently took place (Jones 1981). In 1980, the same phenomenon was observed at Ciawi in Indonesia. The general conclusion was that leucaena can be fed, without toxic effects, to animals that have the necessary microorganisms in their rumen to degrade DHP, although there may be other nutritional problems caused by leucaena's very low sodium content. These latest advances have not been covered by any major publication, and the proceedings of this workshop will clearly be important in this respect.

Ruminal Degradation of DHP

Empirical evidence obtained at Balai Penelitian Ternak (BPT), Ciawi, Indonesia, indicates that virtually complete breakdown of DHP can occur in Indonesian ruminants. The first attempt at studying mimosine–DHP metabolism was with four goats bred within the animal complex at Ciawi and raised on a standard diet that did not include leucaena. When they were given fresh leucaena as the sole feed, they exhibited DHP concentrations of 0.3–0.8% in urine for 4 weeks. Although there was fluctuation, there was no reason to believe that any large changes would occur, and the experiment was discontinued with the conclusion that the animals were *not* able to break down DHP.

My colleagues and I at BPT were on the watch for villages where leucaena was being fed to livestock at high levels without apparent chronic effects. We found one such case: goats were being fed a sole diet of leucaena, obtained from trees on a tea estate. Two of these goats were brought to BPT and were found to have urinary DHP concentrations less than 0.1%. Clearly, these animals *were* breaking down DHP.

About this time (June 1980), we commenced a major 6-month growth study in collaboration with the Agency for Development and Application of Technology. Ongole cattle were fed local Hawaiian-type leucaena at graded levels with a local grass (mostly *Isachne globosa*) (Wahyuni et al., in press). Although primarily a growth trial, the study included measurements of mimosine and DHP in feed and urine and monitoring of serum thyroxine. Unfortunately, full-balance studies were not done until later in the trial.

Urinary DHP was initially generally high among animals on a high-leucaena diet but became much lower after 4 months, with no simple transition being observed. What was clear was that, after 4 months, there was effective breakdown of DHP.

The mean daily data for six animals being

fed 100% leucaena over a 7-day period were recorded. Intake of dry matter was 6.32 kg, mimosine 66.2 g, and DHP 12.9 g. Output of feces (dry matter) was 3.26 kg including 1.37 g mimosine and 1.36 g DHP. Urine output was 5.32 L, with mimosine content being 0.08 g and DHP 0.05 g.

As the amounts of mimosine and DHP in the urine were much less than those in the feces (which probably represents a level too low for effective absorption), the amounts circulating were very small indeed.

Thyroxine concentration did not vary significantly between treatments. There was no evidence of any toxic effects of leucaena, and there was ample evidence that DHP was broken down harmlessly.

Early in 1981, a series of growth experiments with sheep and goats were undertaken after Neville Yates arrived at BPT. Where input and output of mimosine–DHP were monitored, it was found that, virtually from the outset, about 90% of the DHP equivalent was broken down. There was no apparent difference between sheep and goats. The leucaena feed was so free from toxic effects that it became hard to justify further work on mimosine and DHP. However, we did demonstrate in vitro that a ruminal microbial process was responsible for the lowered DHP levels (B. Tangenjaja, unpublished thesis).

When animals that had not been in contact with leucaena for some generations were fed plants from new experimental plantings to which no animals had access, ruminal breakdown of DHP did not occur. It is uncertain how long this situation would have persisted if we hadn't introduced animals from a village where DHP breakdown did occur and then brought in many tonnes of leucaena from the surrounding district to supply feed for a large-scale experiment with cattle. Either of these events could have dispersed the microorganisms responsible for DHP degradation, and, from then on, adaptation occurred spontaneously.

We have, thus, inadvertently and in a lamentably uncontrolled way, arrived at some indications of how easily the ability to detoxify leucaena might be acquired by, and transferred between, animals when the necessary microorganisms are in the surrounding environment.

The major finding overall is that effective breakdown of DHP can occur in Indonesian ruminants and that there is unlikely to be chronic toxicity in any practical situation.

The disjunct distribution of this process around the tropics is, of course, of major interest and importance.

Autolysis of Mimosine to DHP

From the present perspective, it seems that the foregut fermentation of ruminant metabolism is uniquely suited to deal with the toxins of leucaena, either mimosine or DHP. Presumably, this applies also to other food plants that have water-soluble toxins, susceptible to reductive or microbial alteration. Monogastric animals and herbivores with hindgut fermentation absorb water-soluble toxins more readily than do the ruminants.

Because the effects of mimosine and DHP are distinct, one needs to know which of the two is causing toxicity in a given situation. This might seem obvious, but researchers have known for some time that heating, drying, and wilting of leucaena cause some conversion of mimosine to DHP but they haven't produced any literature on how rapid or complete this change can be.

Leucaena seedlings contain an enzyme that catalyzes the hydrolysis of mimosine to DHP, pyruvic acid, and ammonia (Smith and Fowden 1966). We have found the same enzyme in the mature plant, and it can be very active indeed (Lowry et al., in press). The enzyme is present in the leaflets but not in the petiole, rachis, and rachillae; in the lamina of the green pod but not in the raised marginal strands. It is not present in stem or mature seeds. All of these tissues, however, contain mimosine.

Enzyme and substrate occur together in the same cells. This has been shown by autolysis of mimosine under treatments that break cell membranes without grossly disrupting the tissue. For example, simply freezing and thawing the tissues prompts rapid conversion of mimosine at room temperature. Although frosting of leucaena is rare in the field, there have been feeding experiments in which fresh leucaena was stored frozen. Such material would contain very little mimosine when fed to the livestock.

Effect of Elevated Temperatures

When intact leucaena leaves are subjected to temperatures up to 45°C without drying, very little autolysis occurs while the cells are living. At temperatures higher than 70°C, the enzyme is denatured so that, for example, the mimosine in leaves plunged into boiling water would undergo almost no change. The interest-

ing effects occur in the range 55–70°C, high enough to cause plasmolysis in the cell but not high enough to denature the enzyme. Under these conditions, autolysis is very rapid.

Thus, quite simple treatments, such as dipping leaves in water at 60°C for 3 min would change most of the mimosine in the leaflets (but not the stem tissue) to DHP. Fortunately, as the leaflets detach readily and are separated from the stems for production of leaf meal, the distribution of activity favours the production of low-mimosine leaf meal.

Effect of Tissue Disruption

The most obvious way to bring about autolysis without temperature manipulation is to put enzyme and substrate in contact by maceration of the tissue. Under optimum conditions (maceration at 40°C with an equal weight of buffer at pH 7–8), mimosine is largely hydrolyzed within 2 min; by macerating leaves and stems together, one can convert virtually all the mimosine — even that in cells without the enzyme — to DHP.

These findings indicate that any mechanical damage in harvesting and handling leucaena will affect the mimosine and DHP levels. Researchers should be aware of this if feeding animals leucaena as fresh chopped material. Likewise, in the processing of fresh leucaena — for example as protein concentrate — it is unlikely that there is much mimosine present unless enzyme activity has been prevented.

When fresh leucaena is ingested, conditions — maceration, temperature, addition of slightly alkaline saliva — favour rapid autolysis of mimosine. In fact, when we fed fresh, intact leucaena to a goat fitted with an esophageal fistula, we found that 30% conversion of mimosine occurred before the ingesta reached the rumen. There is nothing in the rumen (unlike acid in a monogastric stomach) to stop the autolysis. Thus, microbial activity is not necessary for the conversion of mimosine to DHP when fresh leucaena is used as feed. In other words, ingestion of mimosine from fresh leucaena is always accompanied by ingestion of DHP. It may be possible in nonruminants for the mimosine levels to be subacute and the DHP to exert chronic effects.

Inhibition

Along with sudden heating to temperatures higher than 70°C and contact with acid (the enzyme is virtually inactive below pH 4), drying prevents autolysis. When leucaena is vacuum dried or rapidly air dried, the mimosine is largely unaffected and there is almost no activity on rehydration. Sun drying under clear conditions, as is usually the case in commercial production of leaf meal, leaves the mimosine intact. However, if conditions are humid, temperature elevated, and drying delayed, autolysis can occur. A leucaena sample in a plastic bag in the sun, or a heap of fresh leucaena heating up by its own respiration, will undergo rapid change.

Relevance to Human Nutrition

Leucaena pods and young leaves are used as food in some countries, although problems with mimosine are known. Given the ease of autolysis to DHP and the prevalence of goitre, the possibility that DHP is acting as a previously unknown human goitrogen seems quite real.

Leaf-Meal Production

In some countries, leucaena leaf meal is produced commercially for inclusion in poultry and pig feeds but is usually added at low levels because of the toxic effects associated with mimosine. However, it should be relatively easy to prepare leaf meals with most of the mimosine converted to DHP. This would allow higher rates of inclusion without direct toxicity. It remains to be seen how this works in practice — whether, for instance, the autolysis adversely affects protein quality. The gross composition would, of course, be unaltered, unlike the case with a treatment such as water leaching.

Another way to avoid the adverse effects of mimosine in leaf meal is to use a mixture of species. Most antinutrients, like mimosine and DHP, are secondary compounds, found in one species but not in another. In most cases, there would be no interaction between them. Thus, in a mixture of species, one could have each secondary compound diluted to below the threshold for growth depression. The mixed leaf meal could be used at a higher level than any one of the species in it. In fact, we encountered one leaf-meal dealer who was already doing this in Indonesia, claiming to be blending *Calliandra calothyrsus*, *Sesbania grandiflora*, and *Acacia villosa* with leucaena.

Although we have not yet evaluated mixed-leaf meals, we recognize that their production would be appropriate to the biological resources of tropical countries where there are several species of fast-growing tree legumes available. Mixing species would be technologi-

cally simple, and the additional handling and storage costs would be offset by the larger market that would result. Quality control would be a problem, but leaf-meal composition can be monitored through the same secondary compounds that constitute a utilization problem. The flavonol glycosides have proved to be good indicators in this respect.

Research on Leucaena Forage Production in Malaysia

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In Malaysia, where soils are generally acidic and highly saturated with aluminum, research at the Malaysian Agricultural Research and Development Institute indicates that rhizobial inoculation and lime-pelleting of Leucaena leucocephala *seeds are essential for successful establishment and growth. Screening of leucaena cultivars tolerant to aluminum shows some promising results. Other results of research at MARDI have been reviewed. Studies on mimosine content indicate that it is highest in the shoot tips, first-expanded leaves, flowering heads, and young pods. In the foliage and stems, it declines with age and with increases in the time between leaf harvests. Annual dry-matter yields of between 13.5 t/ha and 21.9 t/ha have been recorded from some promising accessions. A 77-day growth study with goats fed leucaena forage and grass at ratios of 1 : 4, 1 : 1, and 4 : 1 showed a positive correlation between increasing leucaena and live-weight gain, with the highest gain being recorded at 75% dietary leucaena. It was suggested that about 50% dietary leucaena level is suitable for goats. Grazing studies with leucaena–grass pastures have been promising, and daily live-weight gains of Sahiwal-Friesian heifers have averaged 443 g. The results, together, demonstrate and emphasize the potential value of leucaena forage for ruminants.*

En Malaisie, où les sols sont généralement acides et fortement saturés d'alumine, les études effectuées par l'Institut de recherches et de développement agricole de la Malaisie (MARDI) révèlent que l'inoculation du rhizobium et l'enrobage des semences de Leucaena leucocephala *avec de la chaux sont indispensables à l'établissement et au développement satisfaisants du végétal. La sélection de cultivars de* Leucaena *tolérants à l'alumine semble annoncer des résultats prometteurs. D'autres constatations enregistrées par MARDI ont été passées en revue. Les études sur les teneurs en mimosine révèlent qu'elle est élevée surtout aux extrémités des pousses, dans les premières feuilles ouvertes, les sommités florales et les jeunes pousses. Elle diminue avec l'âge dans les tiges et dans le feuillage et avec l'allongement des intervalles entre les récoltes de feuilles. Dans certaines situations prometteuses on a pu relever des rendements annuels de matière sèche variant de 13,5 à 21,9 t/ha. Un test de croissance, durant 77 jours, sur des chèvres nourries de fourrage de* Leucaena *et de graminées en proportions de 1 à 4, 1 à 1 et 4 à 1 a révélé une corrélation positive entre l'accroissement des proportions de* Leucaena *et les gains en poids vif, les plus élevés de ces derniers correspondant à 75 % de* Leucaena *dans le régime. On considère qu'une proportion de 50 % conviendrait bien aux chèvres. Les études sur des pâturages à base de* Leucaena *et de graminées ont été encourageantes, et des génisses Sahiwal-Holstein y ont gagné en moyenne 443 g par jour, poids vif. Globalement, les résultats obtenus démontrent et soulignent la valeur que peut avoir le fourrage de* Leucaena *pour les ruminants.*

En Malasia, donde los suelos son generalmente ácidos y altamente saturados de aluminio, la investigación del Instituto Malasio de Investigación y Desarrollo Agrícola (MARDI) indica que la inoculación de rizobia y el recubrimiento con cal de las semillas de Leucaena leucocephala *es esencial para el establecimiento y el crecimiento. La selección de cultivares de leucaena tolerantes al aluminio muestra algunos resultados promisorios. Otros resultados de la investigación de MARDI ya han sido reseñados. Los estudios sobre el contenido de mimosina indican que el más alto se encuentra en las puntas de los retoños, en las primeras hojas abiertas, en las cabezas florecientes y en las vainas jóvenes. En el follaje y en los tallos desciende con la edad y el aumento del tiempo entre las cosechas de hojas. Se han registrado rendimientos anuales de materia seca entre 13,5 t/ha y 21,9 t/ha en algunas líneas promisorias. Un estudio de crecimiento de 77 días con cabras alimentadas con forraje de leucaena y pastos a raciones de 1 : 4, 1 : 1 y 4 : 1 mostraron una correlación positiva entre el aumento de leucaena y la ganancia de peso vivo, con la mayor ganancia registrada a la dieta de leucaena a 75%. Se sugirió que un nivel de 50% de leucaena en la dieta es apropiado para cabras. Los estudios sobre pastos–leucaena han sido promisorios y las ganancias diarias de peso vivo en terneros Sahiwal–Fresian han totalizado aproximadamente 443 g. Los resultados, en conjunto, demuestran y subrayan el valor potencial del forraje de leucaena para rumiantes.*

Forage from *Leucaena leucocephala* has potential as a means of increasing protein in animal feed, especially in the diet of ruminants. Protein feeds are generally in short supply in Malaysia, and their importance derives from

the fact that inadequate protein intake seriously limits growth of farm animals at a time when maximum offtake is the main objective. These issues prompted a multidisciplinary research program at the Malaysian Agricultural Research and Development Institute (MARDI). Initiated in 1974, its aim is to examine forage production from leucaena, especially the agronomic management of the crop and utilization in feed for ruminants (cattle, goats, and sheep). This paper presents a comprehensive review as well as results of the work done hitherto.

Establishment

In Malaysia, the areas designated for pasture production are generally acidic (pH 4.2–4.5), highly saturated with aluminum, and low in phosphorus and calcium. On such soils, leucaena grows poorly. Good establishment and rapid growth require liming (up to 2 t/ha) together with rhizobial inoculation with CB 81 and lime-pelleting of seeds (Tham et al. 1977).

Pot studies on two soil series, namely Serdang and Bungor, indicated quadratic responses to liming rates, with marked increase in dry-matter yields at 500 kg/ha but leveling at 2000 kg/ha (Tham et al. 1977). Lime-pelleted, inoculated seed significantly ($P<0.05$) outyielded the noninoculated seeds. Without lime application, there were no significant responses to rhizobial inoculation. The nodule numbers and weight were also increased by rhizobial inoculation and liming (Tham et al. 1977).

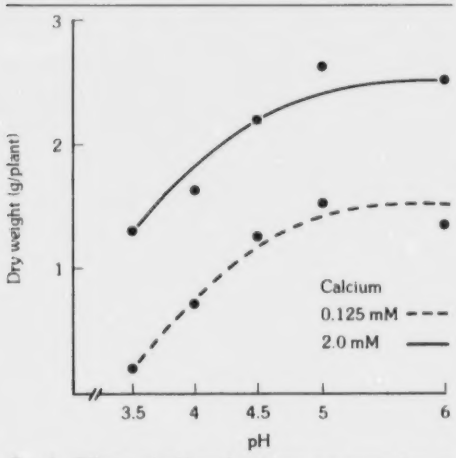

Fig. 1. Effects of pH and calcium concentration in solution on the growth of leucaena (Peru cultivar).

The interactions between lime, phosphorus, and inoculation have also been studied (Tham et al. 1977), and findings were that, in the presence of lime, at 50 kg P/ha, the dry-matter yield of leucaena was significantly greater than at 20 kg P/ha.

Slow seedling growth has been an inherent characteristic of the plant and has posed many establishment problems. Weed control through seed-bed preparation or herbicide treatments is often recommended (Kinch and Ripperton 1962), and nitrogen fertilizer in small quantities has been advocated on poor soils. Studies by Mohd. Najib (personal communication) on the effects of nitrogen fertilizer, clean weeding, and mulching on early establishment of leucaena indicated that mulching, combined with 25 kg N/ha, gave good results.

Influence of pH and Aluminum

Although the plant can thrive on soils with a wide range of pH, it performs better on alkaline, calcareous, clayey soils (Oakes 1968; Hill 1971a). In Malaysia, leucaena is usually grown in limestone outcrops or in the more fertile areas of the coastal alluvium.

Poor growth in acid soils has been attributed to aluminum and manganese toxicity, the effect of hydrogen ions, and calcium deficiencies. To determine the specific effects of soil acidity factors on the growth of leucaena, we tested solution cultures with various levels of pH (3.5–6.0) and calcium concentration. Growth of the Peru variety used in the study increased with increase in pH and calcium concentration (Fig. 1), the optimum pH being about 5; however, there was no single factor, pH or calcium, controlling the growth of leucaena.

Acid soils are often associated with high-aluminum saturation, and those in inland Malaysia exhibit aluminum saturation of 37–86%. The results from solution-culture experiments on aluminum concentration showed that leucaena growth was greatly reduced in solutions containing more than 4 ppm of aluminum (Table 1). The detrimental effects of high aluminum concentration can be ameliorated to some extent by increased calcium levels.

Efforts to identify aluminum-tolerant leucaena were undertaken on the nine top-yielding accessions in the MARDI collection. All the accessions showed reduced yields in response to increasing aluminum, although three accessions performed slightly better than

Table 1. Effect of aluminum and calcium concentration on the growth of Peru in vitro.

	Growth (g/plant)					
	Ca, 1 mM; Al(ppm)			Ca, 5 mM; Al(ppm)		
	0	4	16	0	4	16
Leaf	2.47	1.93	0.10	3.69	2.52	0.46
Stem	1.12	0.73	0.04	1.48	0.48	0.13
Root	1.64	1.66	0.11	1.96	1.60	0.43
RTY %[a]	73.5	60.6	3.5	100	69.6	14.3

[a] RTY % = relative total yield expressed as percentage of maximum total yield.

Table 2. Plant weight response (g/plant) of nine accessions of leucaena grown in nutrient solutions with four concentrations of aluminum.

Accessions/ cultivar	Aluminum concentration (ppm)[a]			
	0	4	8	16
L13	3.30 (100)	2.33 (70.6)	1.61 (48.8)	0.80 (24.2)
L19	3.49 (100)	2.62 (75.1)	1.53 (43.8)	0.88 (25.2)
L42	3.11 (100)	3.08 (99.0)	1.72 (55.3)	0.98 (31.5)
L55	3.52 (100)	2.48 (70.5)	1.59 (45.2)	0.86 (24.4)
L62	3.06 (100)	2.59 (84.6)	1.45 (47.4)	1.02 (33.3)
L65	3.86 (100)	3.10 (80.3)	1.97 (51.0)	0.92 (23.8)
L70	3.16 (100)	2.34 (74.1)	1.39 (43.9)	0.92 (29.1)
L72	2.46 (100)	1.73 (70.3)	1.07 (43.5)	0.71 (28.9)
Cunningham	3.26 (100)	2.55 (78.3)	1.15 (35.3)	0.78 (23.9)

[a] Figures in parentheses refer to relative total yields (RTY) expressed as percentage of the control

the others (Table 2). Screening is being pursued.

Mimosine

From the viewpoint of forage production, the amino acid mimosine is undesirable. It is toxic to nonruminants and, if consumed in large quantities by ruminants, results in thyroid abnormalities (Jones et al. 1976, 1978). Mimosine occurs in all parts of the leucaena plant (Table 3), and our studies indicate that the shoot tip has the highest mimosine content, followed by the flowering heads and young pods. Mimosine content was high in the first-expanded leaf, and the young green stems had the lowest mimosine content in the plant parts examined.

Differences in mimosine content among strains have been reported (Carangal et al. 1955; Brewbaker and Hylin 1965), with con-

Table 3. Concentration (% fresh weight) of mimosine in various parts of Peru and two leucaena accessions.

Plant part	Mimosine concentration (% fresh weight)		
	Peru	55	65
Shoot tips	1.56	1.82	2.88
1st-expanded leaf	1.12	1.18	2.15
3rd-expanded leaf	0.81	0.83	1.72
5th-expanded leaf	0.69	0.79	1.32
9th-expanded leaf	0.54	0.43	1.05
15th-expanded leaf	0.23	0.21	0.34
3rd-stem internode	0.35	0.57	0.90
5th-stem internode	0.16	0.21	0.41
9th-stem internode	0.10	0.10	0.17
15th-stem internode	0.11	0.10	0.07
Flower heads	0.87	1.34	1.57
Young pods	1.07	1.12	1.43

Table 4. Mimosine content (% of dry matter) of first-expanded leaves of leucaena accessions at Serdang.

Mimosine content (%)	Accession
3.5 - 4	1, 18, 21, 38, 64, 66, 76
4.1 - 5	3, 17, 22, 27, 32, 33, 39, 44, 45, 48, 49, 51, 52, 58, 68, 73
5.1 - 6	5, 6, 10, 12, 25, 28, 29, 35, 40, 31, 41, 46, 47, 50, 57, 59 69, Peru, 72
6.1 - 7	2, 4, 9, 11, 13, 15, 16, 19, 20, 23, 30, 34, 36, 37, 42, 43, 55, 61 local, Cunningham
-7	8, 62, 65, 70

tent ranging from 2% to 5% (dry-matter basis). The determination of mimosine levels in the MARDI collection indicated a variation from 0.87% to 2.39% based on fresh weight, equivalent, on a dry-matter basis, to 3.5 - 9.23% (Table 4). Unfortunately, mimosine content was positively correlated with dry-matter production among the promising accessions (Wong et al. in press).

The effect of cutting interval on mimosine content in the leaf and young stems (- 5 mm diameter) has also been studied (Table 5). Mimosine levels declined generally with increased time between cutting, and the change was particularly marked among the cutting frequencies from 2 to 8 weeks. Guevarra et al. (1978) reported that cutting regimens from 10 to 16 weeks did not produce differences in average mimosine content.

Management and Production

Plant size, age of crop, growth period, and floral initiation are some of the characters often adopted as means to determine optimum time of harvest for forage production. Many reports indicate that optimum yield is obtained when the plant is cut after it is 100 - 150 cm high (Anslow 1957; Guevarra et al. 1978). Increasing the time between cuttings enhances dry-matter yield, but the leaf - stem ratio declines — an indication that the proportion of stem is greater in infrequent harvests. Prolonged cutting intervals have never been encouraged for forage production because carbohydrates accumulate in the roots and lower stem and delay the onset of regrowth. These considerations, and an assessment of regrowth associated with the increase in the stem fraction under prolonged cutting intervals, indicate that the optimum time for defoliation would be about 8 - 12 weeks, other things constant.

In field trials, Peru variety, defoliated at 4- and 8-week intervals over 2 years, at 1 m cutting height, produced average annual yields of 3924 kg/ha and 5701 kg/ha, respectively. These yields are comparable with those reported from the dry tropics (Hutton and Bonner 1960; Oakes and Skov. 1962) but lower than the 20 t reported in the humid tropics (Brewbaker et al. 1972; Jones 1979).

There is some seasonal effect on yield (Fig. 2). The sensitivity of forage yields from leucaena during dry spells could be a reflection of the shallow rooting system of the plant caused by the physical soil structure and low pH. In this connection, Mohd. Najib (personal communication) has reported that leucaena plants, defoliated at 2-month intervals and at 0.5-m cutting height, had taproots growing no more than 60 cm deep. The lateral roots were fairly long but were shallow in penetration. Soil moisture is critical, and the importance of rainfall and its distribution pattern on leucaena-forage production has been em-

Table 5. Effect of cutting frequency on the dry-matter yield, leaf - stem ratio, mimosine content (% fresh weight), and regrowth rate of *L. leucocephala*

	Cutting interval (weeks)					
	2	4	6	8	12	16
Dry-matter yield (g/plant)	17.4	32.0	87.9	219.3	459.9	756.5
Leaf - stem ratio	3.03	2.91	1.89	1.40	0.8	0.60
Weekly regrowth rate (g/plant)	8.7	7.3	27.9	65.7	60.2	74.2
Mimosine (% in leaf)	2.52	2.06	1.57	1.06	0.85	0.56
Mimosine (% in stem - 5 mm)	1.11	0.68	0.39	0.17	0.25	0.05

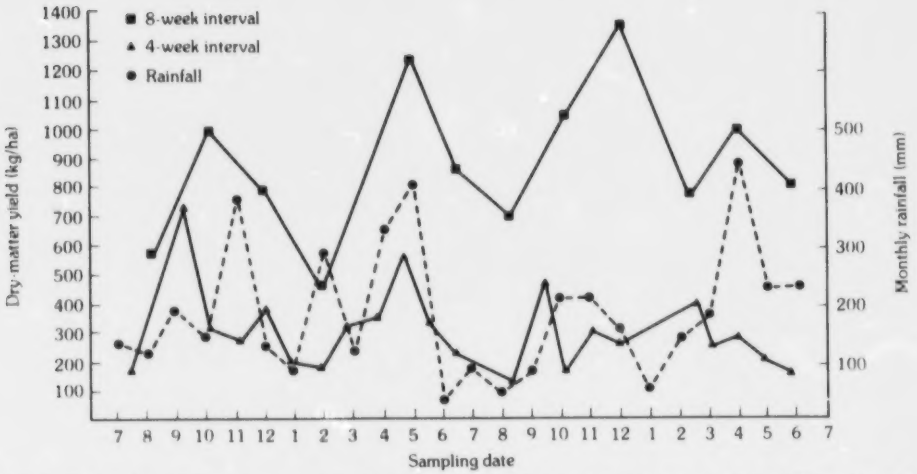

Fig. 2. Effect of rainfall on dry-matter production of Peru cultivar defoliated at 4- and 8-week intervals, July 1980 to July 1982.

phasized despite the fact that the legume is deep-rooted and drought tolerant (Oakes 1968).

Screening of leucaena accessions for improved dry-matter production is one of the objectives of MARDI's leucaena research program. Results of an ongoing experiment involving a number of promising accessions by C.P. Chen (personal communication) indicate that annual dry-matter yields ranging from 13.5 t/ha to 21.9 t/ha could be obtained from the top yielders, defoliated at 2-month intervals and limed at 2 t/ha (Table 6).

Consideration is now being given to the dual-purpose use of leucaena in live fencing and forage production because of the positive implications for the rural areas, especially small farms raising livestock.

Nutritive Value

Two trials investigated the nutritive value of leucaena forage (stems and leaves) when fed ad libitum to livestock. The forage was harvested at 2-month intervals at a cutting height of about 60 cm. Adult goats and sheep of similar live weight (25–26 kg) were also used in an assessment of comparative digestibility (Devendra 1982).

Goats had an average daily dry-matter intake of 51.0–60.9 g/$W^{0.75}$ kg and sheep 39.4–53.7 g/$W^{0.75}$ kg. The digestibility of dry matter for goats was 53.9–56.4%, organic matter 54.1–57.0%, crude protein 44.8–45.0%, and crude fibre 38.5–68.4%. The figures for sheep were dry matter 50.0–50.5%, organic matter 51.1%, crude protein 40.5–46.3%, and crude fibre 31.2–60.2%. Nitrogen retention as a percen-

Table 6. Annual dry-matter yield (t/ha) of promising leucaena accessions defoliated at 2-month intervals and limed at 2 t/ha.

Accession	Annual dry-matter yield (t/ha)
19	13.5
42	14.1
13, 30	15.7
62	17.0
65	18.4
69	18.8
55	21.9
Peru	8.5
Cunningham	11.4

Table 7. Nutritive value of leucaena forage to goats and sheep.

Parameter	Goats	Sheep
Digestible crude protein (%)	9.3–11.0	9.1–10.1
Total digestible nutrients (%)	46.9–67.8	46.7–54.2
Digestible energy (10^6J/kg)	8.66–12.62	8.62–10.00
Metabolizable energy (10^6J/kg)	7.10–10.35	7.07–8.20

Table 8. Effects on growth performance of goats fed *L. leucocephala* (L) and *P. purpureum* (G).[a]

Parameter	100%G	75%G + 25%L	50%G + 50%L	25%G + 75%L
Initial live weight (kg)	12.2	10.1	10.1	10.2
Final live weight (kg)	12.8	12.0	12.6	14.5
Live-weight change (kg)	0.6	1.9	2.5	4.3
Mean live weight (kg)	12.5	11.1	11.4	12.4
Mean daily live gain (g)	11.7a	24.4a	32.9ab	55.8c
Dry-matter intake/day (g)	393.9	404.9	505.3	550.3
Dry-matter intake/weight $^{0.75}$ kg/day	59.7	66.4	81.4	83.4
Dry-matter intake as % of live weight	3.4	4.0	4.8	4.7
Feed efficiency (dry-matter intake/gain)	30.3a	17.1b	15.9b	11.5b

[a] Results refer to the mean value for both males and females (10 goats total). Means in horizontal columns followed by different letters differ significantly ($P < 0.05$).

tage of intake was 22.8–36.3 for goats and 8.7–18.4 for sheep; these differences were significant (Table 7) (Devendra 1982). Continuing work in this program concerns the effect of leucaena forage on the intake and utilization of rice straw.

Animal Performance

A 77-day growth trial was conducted with 40 Katjang × Etawah goats, about 1 year old. The trial had four treatments, replicated twice for males and females in a randomized, block design. The treatments, based on total dry-matter intake (DMI), were napier (*Pennisetum purpureum*) grass (control); 75% grass, 25% leucaena; 50% grass, 50% leucaena; and 25% grass, 75% leucaena.

Leucaena stimulated daily live-weight gain, which was highest ($P < 0.05$) for the animals fed 25% grass, 75% leucaena (Table 8). At this level, however, the mimosine's effects were apparent. No significant differences were distinguishable on the basis of sex, DMI, or body measurements (height at withers, heart girth, and body length). It was concluded that leucaena forage can constitute 50% of the diet of goats (Devendra 1982), which is higher than the level (30%) advocated for steers by Jones (1979).

Grazing studies were undertaken on Peru variety interplanted with native pastures (*Paspalum conjugatum*, *Ottochloa nodosa*, *Centrosema pubescens*, etc.) or *Brachiaria decumbens* in efforts to obtain a highly productive two-canopied pasture. Each leucaena–grass mixture was rotationally grazed at monthly intervals under a two-paddock system and at a stocking rate of 5 Kedah-Kelantan cattle/ha. The mean daily live-weight gains on leucaena–*B. decumbens* and leucaena–native pasture were, respectively, 353 g/head and 305 g/head (Wong et al. 1980). No mimosine toxicity was detected as leucaena formed only about 8% of the total forage available. This level is below that (30%) at which mimosine toxicity symptoms are expressed (NAS 1977).

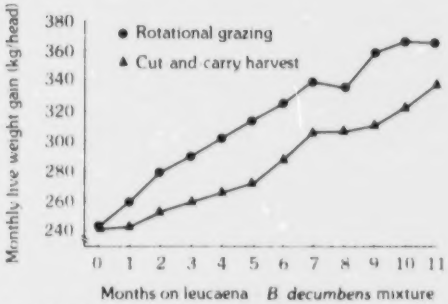

Fig 3. Cumulative live-weight gains of Sahiwal-Friesian heifers on leucaena–B. decumbens mixture at a stocking rate of 5 beasts/ha under rotational and cut-and-carry management systems.

In another experiment currently in progress, the daily live-weight gain of Sahiwal-Friesian heifers, grazing leucaena–*B. decumbens* rotationally, on a four-paddock system, at a stocking rate of 5 head/ha was 443 g/head. The average dry-matter yield, on a 6-week basis, was 2326 kg/ha, with leucaena accounting for approximately 28% of the forage. However, when the animals were stall fed with forage from a similar pasture, the daily live-weight gain was 368 g/head (Fig. 3).

Rotational grazing, thus, appears to give better performance than feeding livestock in stalls. These live-weight gains were comparable with, if not higher than, those obtained from nitrogen-fertilized, improved pasture (Chen et al. 1982) and from a guinea grass–legume mixture (Eng et al. 1978).

Feeding Leucaena to Mozambique Tilapia and Indian Major Carps[1]

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Feed is the costliest factor in fish culture. It is, therefore, necessary to develop balanced, inexpensive feed, preferably from local resources. This is an evaluation of the suitability of leucaena leaf meal in the culture of Mozambique tilapia and Indian major carps in monoculture and polyculture systems. Leucaena leaf meal at 30–60% of the daily feed in both systems had no adverse effects on growth, metabolic, or reproductive behaviour. Carps and tilapia in polyculture existed in harmony.

L'alimentation est l'élément le plus coûteux de la pisciculture. Il importe donc d'élaborer pour les poissons un régime alimentaire à la fois équilibré et économique, de préférence à partir de ressources locales. On trouvera ici une appréciation de la valeur de la farine de feuilles de Leucaena *dans la production de tilapies au Mozambique et de grosses carpes en Inde, en élevages simples ou mixtes. La farine de feuilles de* Leucaena, *à raison de 30 à 60 % de la ration journalière dans les deux procédés, n'a eu aucun effet défavorable sur le développement, le métabolisme ou le processus de reproduction. En élevage mixte, les tilapies et les carpes ont coexisté dans l'harmonie.*

La alimentación es el factor más costoso en la piscicultura. Por tanto, es necesario desarrollar alimentos balanceados y económicos, preferiblemente a partir de recursos locales. Esta es una evaluación de la harina de hoja de leucaena en sistemas de monocultivo y policultivo de tilapia de Mozambique y carpas mayores de India. La harina de hoja de leucaena al 30–60% del alimento diario en ambos sistemas no presentó efectos segundarios sobre el crecimiento, el metabolismo o el comportamiento reproductivo. Las carpas y la tilapia convivieron armoniosamente en policultivo.

To develop low-cost feeds suitable for fish culture, the Bio-Technology Group of Ion Exchange (India) Ltd undertook trials with leucaena leaf meal fed to tilapia and Indian major carps in monoculture and in polyculture systems. Different sizes of aquaria, plastic collapsible pools, and mild-steel (MS) tanks were used. Semifingerlings of *Sarotherodon mossambicus*, *Labeo rohita*, and *Cirrhinus mrigala* were procured from the Aarey Fish Farm. Fingerlings of *Catla catla* were obtained locally. Three sets of experiments were conducted. Also, a polyculture pond in which fish were fed leucaena meal was observed. For each set, a control was used for comparison. The various feeds were autoclaved at 1.05 kg/cm^2 (15 pounds/square inch) for 40 min. In addition to pelletized feed, *Hydrilla* culture was introduced at the beginning of each experiment. Percentage survival, weight gain, and reproductive behaviour were monitored. Aeration in all these sets was for 4–6 h/day, and water was changed every 10–15 days.

In the first set of experiments (polyculture), four carps and six tilapia were introduced into a rectangular aquarium 0.9 m × 0.425 m × 0.3 m containing 75 L water. The daily feed consisted of 65% leucaena leaf meal, 30% standard balanced pellets, and 5% fish feed at 5% total body weight. The composition of the standard balanced pellets was protein 36%, fat 2%, fibre 6%, acid-insoluble ash 4%, lysine 2%, methionine and cystine 1%, calcium 3%, phosphorus 1%, and fillers 45%. The metabolizable energy was 2500 kcal/kg. The composition of fish feed was: bone meal 65% and fish meal 35%.

The feed in the control set consisted of 95% standard balanced pellets and 5% fish feed at 5% body weight daily. The experiments lasted 104 days.

The second set of experiments, also a polyculture system, comprised 8 carps and 42 tilapia in circular, plastic, collapsible pools 1.8 m in diameter, 1.2 m high, each containing 2120 L water. The treated feed was leucaena leaf meal 50%, groundnut-oil cake 25%, and wheat bran 25% at 5% body weight. The control feed was groundnut-oil cake and wheat bran in equal proportions. The experiments lasted 160 days.

[1] This paper was presented by G.S. Ranganathan, President, Ion Exchange (India) Ltd, at the workshop.

The third set of experiments comprised 26 tilapia in an MS tank 1.2 m in diameter, 0.9 m high, with 590 L water. The treated feed was 30% leucaena leaf meal and 70% standard balanced pellets. The control feed was 100% standard balanced pellets. The experiments lasted 120 days.

In addition, the effects of leucaena leaf meal were observed in the fattening pond (19.5 m × 9.0 m × 1.8 m, water depth of 0.55 m). A polyculture of 185 carps and 15 male tilapia was established. The daily feed was 50% leucaena leaf meal, 25% wheat bran, and 25% groundnut-oil cake at 5% body weight (in the form of cakes 2.5 cm × 2.5 cm × 2.5 cm that dissolve in 4 - 6 h). These cakes were tied to a string at three water levels — bottom, middle, and surface. *Hydrilla* culture was introduced in January 1982. First, the pond was fertilized with 50 kg cowdung, 2 kg urea, and 2 kg superphosphate (November 1981), and six ducks manuring the pond helped produce plankton. Sampling was done monthly so that morphological parameters could be monitored. Two rows of leucaena seedlings were transplanted (1 m × 1 m) around the pond in January 1982 so that the leaf litter could be easily added.

Results and Discussion

In the first set of experiments, the feed uptake and growth of the leucaena-fed carps and tilapia (in 104 days) did not differ significantly from those of the controls (Table 1). Survival rate was 100%. After 95 days, tilapia hatched in both the control and the treated aquaria. The number of fry per female in both was about the same. Leucaena leaf meal at 65% level had no adverse effect on weight gain, reproductive behaviour, or general metabolism. From semifingerling stage to maturity, fish in the treated tank seemed to like nibbling leucaena feed tablets. Carps and tilapia existed in harmony.

In the second set of experiments, leucaena leaf meal at 50% in the treated tank had no observable adverse effects on the growth of carps or tilapia (Table 2). Survival rate was about the same for the leucaena-fed and control groups. Hatching occurred in 95 - 100 days in both control and treated pools. The number of fry was about the same. The metabolic behaviour, i.e., movement and excreta, was normal in both cases. Carps and tilapia were in harmony. The experiments indicated that fish, fed 50% leucaena leaf meal

Table 1. Average growth of fish fed leucaena leaf meal (65% of the diet) compared with controls, each group comprising four carp and six tilapia in an aquarium (9 m × 0.425 m × 0.3 m).

Date (day/month/year)	Control			Treated		
	Length (cm)	Breadth (cm)	Weight (g)	Length (cm)	Breadth (cm)	Weight (g)
11/1/82	3.0	0.82	3.1	3.2	0.87	3.18
11/2/82	4.5	0.97	4.95	4.8	1.06	5.10
11/3/82	7.9	1.40	8.85	8.1	1.80	9.15
11/4/82	9.85	2.60	15.00	10.00	2.65	16.70
25/4/82	10.25	2.72	20.80	11.00	2.78	22.20

Table 2. Average growth of fish fed leucaena leaf meal (50% of the diet) compared with controls, each group comprising 8 carp and 42 tilapia in a plastic pool.

Date (day/month/year)	Control			Treated		
	Length (cm)	Breadth (cm)	Weight (g)	Length (cm)	Breadth (cm)	Weight (g)
14/1/82	3.18	0.75	3.20	3.02	0.74	3.15
14/2/82	5.60	1.25	5.90	5.50	1.30	5.00
14/3/82	10.80	1.85	11.23	10.36	1.70	10.95
14/4/82	11.08	2.12	20.22	11.10	2.15	20.50
14/5/82	13.50	2.80	26.80	13.80	2.78	26.66
14/6/82	14.60	2.95	36.45	14.56	2.90	35.50
24/6/82	15.00	3.10	42.50	14.96	3.04	40.60

Table 3. Average growth of tilapia fed leucaena leaf meal (30% of the diet) compared with controls in mild-steel tanks (1.2 m diameter × 0.9 m high).

Date (day/month/year)	Control			Treated		
	Length (cm)	Breadth (cm)	Weight (g)	Length (cm)	Breadth (cm)	Weight (g)
14.1.82	2.9	0.75	3.20	2.98	0.78	3.22
15.2.82	5.02	1.10	6.85	5.28	1.22	7.45
15.3.82	12.08	1.50	14.50	13.08	1.65	15.09
15.4.82	14.06	2.85	28.00	15.08	2.90	30.50
15.5.82	15.85	2.96	36.80	16.20	3.10	38.90

Table 4. Average length and weight of fish fed leucaena leaf litter from trees (at 1 m × 1 m spacing) around the fattening pond (19.5 m × 9.0 m × 1.8 m).*

Date (day month year)	*Labeo rohita*, *Cirrhinus mrigala*		*Catla catla*		*Sarotherodon mossambicus*	
	Length (cm)	Weight (g)	Length (cm)	Weight (g)	Length (cm)	Weight (g)
8.12.81	3.90	4.10	9.40	27	9.60	10.50
8.1.82	10.25	12.50	12.50	60	11.50	15.60
8.2.82	11.75	16.68	16.65	80	12.90	25.70
8.3.82	13.60	30.80	17.85	120	13.85	40.60
8.4.82	14.80	56.20	18.90	250	14.08	59.20
8.5.82	16.56	70.40	25.50	335	16.90	75.40
8.6.82	17.80	88.60	28.96	400	17.50	98.20
8.7.82	19.60	103.24	30.28	468	18.90	118.00

* Polyculture included 90 *L. rohita*, 80 *C. mrigala*, 6 *C. catla*, and 15 (males only) *S. mossambicus*.

at 5% body weight daily, experienced no adverse effects.

Similarly, in the third set of experiments, leucaena leaf meal (30% of feed) had no adverse effects on the tilapia (Table 3). Reproductive behaviour and metabolic rate in control and treated tanks were similar. Hatching in both tanks occurred about the same time, and fry were almost the same in number. The excreta pattern and survival rate of leucaena-fed fish were also similar to those of controls.

In the fattening pond, fish grew well on 50% leucaena leaf meal (Table 4); the duck manure produced the anticipated plankton bloom, and the planting of leucaena around the pond provided shade and reduced the temperature of the water.

Conclusions

The findings from these studies indicate that leucaena leaf meal from 30% to 65% total diet may be included in tilapia and carp feeds with no adverse effects on growth, metabolic, or reproductive behaviour. Similar observations were recorded by Cruz and Laudencia (1978), when they found that Nile tilapia showed normal gain and fertility when leucaena leaf meal was placed inside feeding rings at levels of 2% and 4% of body weight daily. Furthermore, Brewbaker and Hutton (1979) suggested planting leucaena trees around aquaculture ponds to provide desirable shade, protection from wind, and leaf litter that would add nitrogen to the ponds. In the present investigation, planting leucaena around the pond seems to have been beneficial.

We are grateful to G.S. Ranganathan, President, Ion Exchange (India) Ltd, for outlining the program of work and providing guidance, as well as editing this paper. We acknowledge the earlier efforts of the late Vinod D. Pathak in these investigations.

Leucaena Leaf Meal and Forage in Thailand

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This paper deals with leucaena as a component of animal-feed production in Thailand. Leucaena for forage is being promoted throughout the country in a backyard-pasture scheme. The compound feed for swine and poultry usually contains 3 - 5% leucaena leaf meal, but that for dairy cattle can safely include 15%. There are 19 leaf-meal mills in the country, producing approximately 6 × 10^4 t annually. The quality of the product is low, and protein content in leaf-meal samples ranges from 11.2% to 21.5%, although the pure leaves may have as much as 17 - 28%. Average mimosine content in the leaves is 3 - 5%, with great variation between species. Toxicity from mimosine and its derivative DHP has been observed in studies of young cattle fed high levels of fresh leucaena leaves for 8 months in Thailand, and toxicity in sheep has also been observed. Nevertheless, recent tests on cattle fed high levels of fresh leucaena leaves have indicated that they are able to degrade both mimosine and DHP and may be able to thrive on the diet.

Cet exposé traite du Leucaena comme constituant des aliments du bétail produits en Thaïlande. On encourage dans tout le pays l'emploi du Leucaena comme fourrage dans le cadre d'un programme de pâturages pour les petites exploitations. Les aliments préparés pour les porcs et la volaille contiennent généralement de 3 à 5 % de farine de feuilles de Leucaena, mais ceux destinés au bétail laitier peuvent, sans danger, en contenir jusqu'à 15 %. Le pays compte 19 moulins préparant cette farine et dont la production annuelle est d'environ 6 × 10^4 t. Le produit est de qualité médiocre, la teneur protéique des échantillons prélevés variant de 11,2 % à 21,5 %, alors que les feuilles à l'état pur peuvent en contenir de 17 à 28 %. La teneur moyenne en mimosine des feuilles oscille entre 3 et 5 %, avec d'importantes variations entre les espèces. On a relevé des cas de toxicité par la mimosine et son dérivé, DHP, en observant de jeunes bovins qui avaient consommé de grosses quantités de feuilles fraîches de Leucaena pendant 8 mois. D'autres cas ont été relevés chez des moutons et des vaches. Des épreuves préliminaires sur des bestiaux de Thaïlande, mis à un régime à base surtout de feuilles fraîches de Leucaena, permettent de croire que ces animaux peuvent décomposer la mimosine ainsi que le DHP et qu'ils pourront ainsi profiter avantageusement de ce régime.

Este trabajo se ocupa de la leucaena como componente en la producción de alimento animal en Tailandia. La leucaena para forraje está siendo impulsada en el país dentro de un plan de pasturas caseras. El compuesto para cerdos y aves contiene generalmente 3 - 5% de harina de hoja de leucaena, pero el del ganado lechero puede incluir sin peligro 15%. Hay 19 molinos de harina de hoja en el país que producen aproximadamente 6 × 10^4 t anualmente. La calidad del producto es baja, y el contenido de proteína en las muestras de harina de hoja oscila entre 11,2% y 21,5%, aunque las hojas puras pueden tener tanto como 17 - 28%. El contenido promedio de mimosina y su derivado es de 3 - 5% con gran variación entre especies. La toxicidad de la mimosina y su derivado DHP ha sido observada en estudios realizados en Tailandia sobre ganado joven alimentado con altos niveles de hojas de leucaena fresca por 8 meses. También se ha observado la toxicidad en las ovejas. Aun, recientemente, pruebas preliminares en ganado alimentado con altos niveles de hojas de leucaena fresca han indicado que el ganado en Tailandia puede degradar tanto mimosina como DHP y sobrevivir con la dieta

Although leucaena has been known in Thailand for several hundred years, its value was not appreciated until quite recently when commercial poultry and swine production were firmly established in the country. The plant is known in Thailand as "Kratin" and believed to have been introduced some 500 years ago via India or Kampuchea (Manidool 1968). It spread widely and now grows naturally in many areas from low terrain to 1000 m above sea level. The early introduction, judged by the form and characteristics of the existing plant, is believed to have been from a small Hawaiian type. The widely grown strain today is short, bushy, well-branched, producing seed freely. There are no records of new introductions until 1962 when seeds of Peru cultivar were obtained from Australia. In 1967, nine other strains consisting of Ivory Coast (PI 286295 No. 62); El Salvador; Australia; Taiwan; New Guinea 70, 71, and 72; and Colombia (Manidool 1968) were introduced.

In 1976, seeds of Cunningham cultivar were introduced by the Office of the Livestock

Development Project in Khon Kaen. During 1977–80, several K lines were introduced by the Department of Forestry and the Thailand Institute of Scientific and Technological Research (TISTR) mainly for wood and forestry purposes.

Early uses of leucaena in Thailand were mainly as firewood, live fencing, and, to a lesser extent, human food. Villagers in the rural areas usually grow leucaena along the boundary of their homesteads to serve as a fence. Branches and twigs are cut, collected, dried, and stored for fuel for family use. An estimated 5–6 t/ha of dry twigs are obtained. Young leucaena shoots and pods are relished by the Thais and are eaten as green vegetables. They are served with *namprik*, a traditional favourite that is made with shrimp paste, spices, and lemon juice.

In southern Thailand, the young shoots and pods are eaten together with *Khao Yam*, another traditional dish. Khao Yam is prepared with boiled rice and a mixture of fish soluble; crushed, dried shrimp; and roasted coconut meat.

Unlike the *tempe* of Indonesia, a fermented product of leucaena seed, young pods and shoots used for human food in Thailand are eaten fresh. Normally, the young shoots are sold in bunches in the market at US$ 0.20–0.30/kg. Usually, the shoots are harvested from the fence or backyard garden, but many Thai families, even in the cities, keep one or two leucaena trees just for vegetable purposes.

One major role for leucaena at present is as livestock feed, particularly leaf meal. Use of leaf meal in poultry feed began during the 1950s when large-scale poultry farming was well established, and it was so successful that eggs became an export commodity for which Malaysia and Hong Kong were, and still are, the main markets. Also, parallel to this was swine production, which was rapidly becoming a commercial endeavour. The first major producing area was Kanchanaburi Province, about 130 km west of Bangkok. Leucaena leaf meal is incorporated into feed mixtures for both poultry and swine, and, today, 35 feed mills operate in Thailand (Manidool 1981). Leucaena leaves are high in protein, minerals, and carotene. Protein content is as high as 20.7–28.2%.

Unfortunately, the leaves also contain mimosine, which produces toxicity in many animals fed leaf meal (Brewbaker and Hylin 1965; Jones et al. 1976). For example, at Pakchong Forage Crop Station, sows fed daily with fresh leucaena leaves for 8 months produced an average four piglets, whereas they produced an average seven after a year of exclusion of the leaves from the ration. For this reason, a maximum 5% leucaena leaf meal is recommended for pig and poultry feed mixtures and 15% for dairy cattle and other ruminants (Table 1).

Table 1. Ingredients (%) in feed formulas using leucaena leaf meal for three kinds of stock.

Ingredients	Swine	Poultry	Dairy cattle
Rice bran	20	12	30
Cornmeal	47	34	20
Leucaena leaf meal	4	4	15
Copra meal	6	8	—
Soybean-cake meal	12	21	—
Fishmeal	10	15	—
Ground shell	1	0.5	—
Salt	0.5	0.25	—
Bone meal	—	0.5	—
Kapok cake meal	—	—	30
Urea	—	—	2
Minerals	—	—	5

All the leucaena leaf meal produced in Thailand at present incorporates leaves of the local variety, which gives low yields compared with some of the introduced strains (Manidool and Torsakul 1977). Leaf meal is produced mainly by smallholder farmers (0.5–1 ha), although, recently, there has been a move toward large-scale leaf-meal production for export.

Leucaena for leaf-meal purposes is grown in rows usually about 30–50 cm apart. Shoots and leaves are harvested together by hand every 50–60 days, although the time is shorter on large farms. Chopped, dried for 2–3 days, and sold to the mills, dried leaves fetch about US$ 50/t, and the average farmer earns $313/ha yearly. The milled product is sold to

Table 2. Percentage of stems and protein in dried leucaena leaves from six selected farms.

Farm location	Stem pieces (%)	Protein (%)
Kanchanaburi	41.3	12.5
Kanchanaburi	42.2	12.3
Kanchanaburi	40.1	11.2
Pakchong	25.2	18.2
Pakchong	23.1	19.3
Chiang Mai	22.5	21.5

feed producers for up to $110/t. At present, there are 19 leaf-meal mills operating in the country, producing about 6×10^4 t annually.

The quality of leaf meal from the majority of the mills is poor, because as much as 42% of the milled product is stems. The protein content in samples of leaf meal from the mills ranged from 11.2% to 21.5% (Table 2). There is no quality control on leaf-meal production and no price incentive to produce high quality.

Backyard Forage-Crop Program

During 1976–80, a livestock development project was launched to improve the cattle and buffalo production in northeast Thailand. The project was supported financially by a loan from the World Bank. One of the components of the project was to develop pastures. Because most landholdings in the country are extremely small, a backyard pasture program was adopted, and leucaena was one of the legume species used. The aim was to provide sufficient protein feed for the livestock. The farmers were encouraged to grow leucaena on wasteland, around their homes, or on idle land. In 1981, about 84 000 seedlings were distributed to 6800 farmers.

The program has now been extended to other areas, especially in the south, where some 10 000 seedlings are ready for distribution. In this program, the farmers are recommended to feed leucaena leaves (1 kg/day) to cattle and buffalo in addition to traditional feeds.

In 1981, about 4 t of leucaena seeds were produced by the Department of Livestock, the majority being from the local strain. The Department provides farmers with 1 kg of seed free of charge but charges $ 1/kg for additional seed from the introduced strain and $ 0.50/kg for seeds from the local strain. However, the price varies among agencies and may be as high as $ 5/kg for seeds for wood-production purposes, e.g., for K8.

Trials

So far, only two variety trials have been carried out on leucaena for forage production in two different locations — Pakchong (Manidool 1968) and Chiang Mai. Cunningham, grown at Chiang Mai, and cut to 40 cm high at 3-month intervals, produced the highest yield (Table 3).

In 1980, Sampet also studied cutting height and interval for Cunningham, but overall yields were lower than in the earlier study because of fluctuation in rainfall (Table 4).

The first planned feeding trial with leucaena for cattle feed was carried out by the Office of Livestock Development Project, Khon Kaen. The objective was to study the effect of high levels of green leucaena leaves on the growth of yearling cattle. The trial comprised 15 head of cattle, divided into groups of 5. One group received 40% rice straw, 60% concentrates (rice bran; cornmeal, soybean meal, and minerals). The second group received 50% green leucaena leaves, 40% rice straw, and 10% rice bran; and the third group received 1 kg fresh leaves every evening after being allowed to graze marginal areas. At the end of 7 months, average daily weight gains were 0.641, 0.429, and 0.479 kg/head for the respective groups. After 8 months, animals in the second group

Table 3. Average yields and protein contents of leucaena varieties in Thailand (Manidool and Torsakul 1977; Sampet 1979).

Variety	Dry matter (kg/ha)	Protein (%)	Ca (%)	P (%)	Location
Australia	3351.8	22.0	2.5	0.15	Pakchong
Local	2795.6	21.9	2.8	0.16	Pakchong
Ivory Coast	9437.5	21.2	2.9	0.15	Pakchong
El Salvador	5813.7	21.5	3.0	0.14	Pakchong
New Guinea 70	4769.3	23.8	2.6	0.15	Pakchong
New Guinea 71	5261.2	23.3	3.2	0.14	Pakchong
New Guinea 72	4098.1	21.6	2.8	0.15	Pakchong
Taiwan	2975.6	21.1	2.9	0.14	Pakchong
Hawaiian giant	8195.2	21.0	3.0	0.13	Pakchong
Colombia	1896.2	20.7	3.2	0.14	Pakchong
Local	5753.0	28.2	—	0.25	Chiang Mai
Peru	10800.0	27.1	—	0.25	Chiang Mai
Cunningham	12177.0	26.9	—	0.24	Chiang Mai
Hawaiian giant	9965.0	26.0	—	0.23	Chiang Mai

Table 4. Edible dry-matter yields (t/ha) of leucaena after 24 weeks of being cut at three different heights and intervals.

Height (cm)	Cutting interval (weeks)		
	4	6	8
5	3.47	4.09	4.92
25	4.99	5.89	5.31
50	6.79	7.16	7.25

showed signs of toxicity — weight loss, low appetite, and excessive salivation (Office of Livestock Development Project 1981). The other two groups continued to make progress.

In a preliminary test, sheep of a local breed showed toxicity signs early in feeding experiments with high levels of leucaena leaves but recovered well within 2–3 months. This test is being continued at the Pakchong Forage Crop Station. It commenced 15 June 1982: three sheep were fed 50% fresh ruzi grass and 50% fresh leucaena leaves, and, within 40 days, two of the sheep began losing hair and experiencing weight loss. By mid August, however, normal wool growth resumed and has continued.

I (1971) carried out a trial on four native sheep at Pakchong Forage Crop Station to determine the digestibility of the local leucaena strain. My findings indicated that an average 63.5% of the dry matter was digestible, and average daily intake was 402.7 g/head. Tests on other leucaena strains are being carried out at the same station.

Table 5. Mimosine content of some leucaena strains grown at Pakchong.

Strain	Mimosine (%)	
	Leaf	Stem
Local	6.30	3.78
Hawaiian giant	7.98	5.23
El Salvador	5.12	5.58
K67	6.95	4.28
Taiwan	4.80	2.68
Australia	5.15	3.43
New Guinea 70	6.55	2.23
New Guinea 71	7.22	4.47
New Guinea 72	4.33	2.50
Ivory Coast	6.65	5.11
Cunningham	4.62	2.48
Colombia	5.45	3.58

Mimosine and DHP

According to the Thailand Institute of Scientific and Technological Research, mimosine content in the K8 strain grown in Bangkok is unusually low, being only 2.12%. A team of chemists of a division of the Animal Nutrition Laboratory are studying the contents of mimosine in different strains of leucaena grown in different areas of Thailand. The data have not yet been published, but the preliminary finding is that there is wide variation in the mimosine contents (Table 5). The average values for leaf lamina and leaf stalk were 3.7% and 5.9% respectively (Sumontip Boonnak, personal communication).

The amino acid mimosine is degraded to DHP, which, if not further degraded, has a powerful goitrogenic action. Studies by Jones and Megarrity (1981) have confirmed that there are differences in ruminal metabolism of mimosine and its derivative DHP in different regions of the world.

In cooperation with R.J. Jones of the Davies Laboratory in Australia, samples of urine from cattle fed high levels of leucaena leaves from Thailand were examined for DHP, and it was found that the levels were almost nil. Thus, in Thailand, cattle seemed to harbour microorganisms that are capable of degrading DHP and, thus, eliminating its goitrogenic effects.

Conclusion

In Thailand, leucaena has played an important role for many years, particularly in animal feed, and, at present, fairly large amounts of leaf meal from the legume are being produced by small farmers. The quality of the leaf meal is low, however, because the woody stems of the plant constitute a large portion (as much as 40% in some places) of the meal. Research on leucaena in animal feed in Thailand has been fragmented to date, with work being undertaken on agronomy, animal nutrition and growth, composition, toxicity, etc. I believe strongly that a coordinated program is needed for efficient use of resources (both human and material).

Beef Production on *Leucaena–Imperata* Pastures and Cattle Feeds on Small Farms in the Philippines

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Animal production in the Philippines could be improved substantially by the use of leucaena-based pastures. Beef production on Imperata *leucaena pastures is three times that of production from* Imperata *alone, and more than 400 kg live-weight gain has been obtained from Guinea grass leucaena pastures. At present, however, leucaena's use on small farms varies, depending on the cropping system. The feeds for livestock on these farms are directly related to crops grown because farmers extensively use farm by-products and weeds as animal feeds.*

La production animale des Philippines pourrait être sensiblement améliorée en multipliant les pâturages à base de Leucaena. *Le rendement des bovins de boucherie dans des pâturages mixtes d'*Imperata–Leucaena *est trois fois plus élevé que dans les pâturages d'*Imperata *seule et l'on a obtenu des gains pondéraux dépassant 400 kg sur mélange d'herbe de Guinée et* Leucaena. *A l'heure actuelle, cependant, l'utilisation de cette légumineuse par les petits exploitants varie d'après les systèmes culturaux. L'alimentation des bestiaux dépend directement des cultures pratiquées, les cultivateurs utilisant largement les sous-produits de leurs récoltes et les plantes adventices pour nourrir leurs animaux.*

La producción en Filipinas podría mejorarse sustancialmente mediante el uso de pasturas basadas en leucaena. *La producción de carne con base en pasturas de* Imperata–leucaena *triplica la producción a partir de la* Imperata *sola, y se han obtenido ganancias de peso vivo superiores a 400 kg con Guinea–leucaena. Actualmente, sin embargo, el uso de* leucaena *en las pequeñas fincas varía según el sistema de cultivo que se use. Los alimentos para ganado en estas fincas están directamente relacionados con los cultivos que se siembran porque los agricultores usan de manera amplia los subproductos y las malezas como alimento animal.*

Two types of livestock-production systems exist side by side in the Philippines. These are backyard (smallholders or subsistence farmers) and commercial livestock raising. The backyard sector accounts for the majority of the livestock population, but both sectors contribute to the total industry and are complementary.

Part of the livestock coming from ranches finds its way into commercial feedlot operations, but, increasingly, the weanlings and yearlings are brought to the livestock market in Batangas and Pangasinan, where they are purchased by small farmers for fattening or for use as draft animals. The two provinces, particularly Batangas, popularized the backyard or small-scale livestock-production system that is now being adopted by other provinces with the support of the government (small farmers' credit scheme).

Live-Weight Gains

The Philippines has $3.5 \cdot 10^7$ ha of open grasslands, of which about 10^6 ha are grazed by livestock. The predominant vegetation is *Imperata cylindrica*. In recent years, pasture-development efforts have been directed toward incorporating legumes into the native pastures. Generally, the legumes that have been used are *Centrosema*, Schofield stylo, *Siratro*, and *Leucaena leucocephala*, popularly known as ipil-ipil in the Philippines.

Imperata–Leucaena Pastures

The Bureau of Animal Industry has investigated the value of leucaena in this regard. In one experiment, carabaos grazing *Imperata* (three animals, 10.66 ha) were compared with those on *Imperata–Leucaena* (eight animals, 5.34 ha and 4.00 ha). The study was conducted in Bohol, which experiences rain throughout the year but is relatively dry during March, April, and May. All pastures were grazed for 10 days, followed by 30 days' rest. After 315 grazing days, average daily gain on *Imperata* pasture at 0.75 animal units/ha was 220 g, whereas that on *Imperata–Leucaena* pastures was 350 g and 280 g at 1.5 and 2.0 animal units/ha, respectively.

Total gain on *Imperata* pasture stocked at 0.75 animal units/ha was 68.12 kg/head and that on mixed pastures at 1.5 and 2.0 animals/ha was 111.94 and 87.4 kg/head, respectively. The figures for live-weight gain were 51.09, 167.91, and 174.84 kg/ha, respectively, for the three treatments.

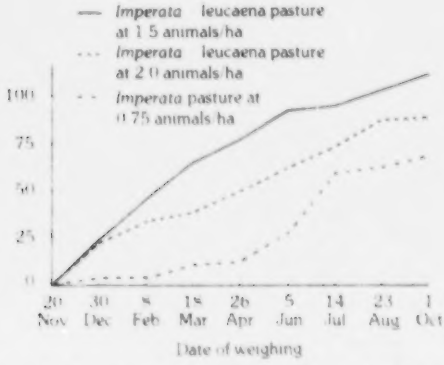

Fig 1 Cumulative live-weight gain (kg head) of carabaos on Imperata *leucaena pastures*

Although the animals on all pastures progressively gained weight, the highest rate of gain throughout the grazing period was observed on the mixed pasture at a stocking rate of 1.5 animal units/ha (Fig 1). Animals grazing only native pasture had the lowest rate of gain overall but had the highest rate of gain at the early part of the rainy season.

Fresh herbage yields of the mixed pastures were 2.8 times ($P < 0.05$) those of the native pasture alone, with the leucaena component constituting more than 50% of forage yields from the mixed pastures.

Guinea Grass–Leucaena Pasture

A demonstration trial at the Alabang Stock Farm (15 km south of Manila) indicated that a hectare of Guinea grass–leucaena pasture would support two head of cattle during the dry season (November–May) and five head during the rainy season (June–October), with an average daily gain of 560 g/head. The pasture is divided into four paddocks, with each paddock being grazed 10 days on and 30 days off. This pasture has been grazed for 3.5 years and is still in excellent condition. No symptoms of mimosine toxicity have been observed, even on animals grazing the pasture for more than a year. At a conservative estimate of average daily weight gain of 500 g/head, the pasture could annually produce live-weight gains of 440 kg/ha, valued at 8360 pesos (at P19/kg) or about US$ 1000.

Cropping Patterns

The most distinctive feature of the livestock industry in the Philippines is the fact that most production comes from subsistence farms rather than from commercial operations. All the 5 million carabaos in the country are found on small farms and easily half of the 2 million cattle. This means that the livestock are only part of the production system, complementing crops. The cattle or carabaos provide draft power for cultivation and transport. The by-products from crops as well as the weeds from croplands serve as feed for the livestock.

The principal product is crops, and livestock is ancillary. The farmers till small pieces of land and raise a few head of cattle or carabaos (Table 1). A majority have landholdings of less than 2 ha, with 22–42% having less than 1 ha. The cattle holdings are also small, with a majority of farmers having only one animal. Some farmers feed their animals leucaena along with the crop by-products and weeds. The bulk of the feeds is directly related to the crops grown.

Table 1 Land and cattle holdings of 315 farms in four Philippine villages

	Luyos Tanauan, Batangas (% of total)	Galamay-Amo San Jose, Batangas (% of total)	Pacifico Sta. Teresita, Batangas (% of total)	Matipunso San Antonio, Quezon (% of total)
Area (ha)				
<1.0	42	22	33	40
1.0–1.9	52	48	48	34
2.0–2.9	6	20	15	26
>3.0	—	10	4	0
Cattle (head)				
1	42	92	48	74
2	54	8	16	23
3	4	—	36	3

Cattle grazing leucaena have shown good weight gains when toxic effects from the mimosine DHP are not present

On farms where rice and corn are the primary products (Galamay Amo, San Jose, Batangas), *Paspalum conjugatum* constitutes more than 38% of the feed from June to August, gradually decreasing thereafter to 1% and then increasing again to 30% in November May. Annual grasses like *I. cylindrica*, *Apluda mutica*, *Digitaria microbachne*, *Dactyloctinium aegyptium*, *Echinochloa colona*, and *Rottboellia exaltata*, which are associated with rice, corn, and cultivated crops, are abundant and are gathered by farmers from July to September. Broadleaves, particularly *Synedrella nodiflora*, *Pseudoelephantopus tomentosus*, *Triumfetta semitriloba*, although not making up a large proportion of the feed, are always a component. In December April, crop weeds become scarce and are replaced by fresh corn stalks and corn stovers. Other components are coconut frond, jackfruit peelings, banana leaves, and pseudostem. Leucaena is not extensively used by these farmers.

In Pacifico, Santa Teresita, Batangas, sugarcane is the principal crop and main source of feed, especially during the milling season (November April). *Imperata* is gathered throughout the year in small amounts but constitutes a higher proportion (up to 50%) of feed during August and October. Other grass species, such as *Ageratum conyzoides*, *P. conjugatum*, *E. colona*, *Eleusine indica*, and some broadleaf species, such as *Elephantopus tomentosus*, and *S. nodiflora*, are fed to the cattle year round, with small amounts of legumes like *Centrosema pubescens* and *Desmodium* sp. Other crop by-products like banana leaves and corn fodder are also given in small amounts. Chopped and ground *L. leucocephala* and *Aeschynomene indica* mixed with rice bran and commercial feeds are offered daily in "Supa." This pattern of feeding gives good gains, because it increases intake of both dry matter and nutrients.

In the coconut cropping system found in Matipunso, San Antonio, Quezon, *P. conjugatum* and *Cyrtococcum accrescens* are among the basic feeds (12 20%) for cattle in June December. The amount varies every month, but the grasses form part of the diet throughout the year. Among the leguminous species, *Centrosema* is a dietary constituent throughout the year particularly in June, with small amounts of *A. indica* and *Desmodium*

sp. in November. Broadleaves like *S. nodiflora*, *T. semitriloba*, and *Commelina benghalensis* are gathered in July–November, and *Mekania cordata* is always part of the feed. From December to June, feed is scarce, and farmers resort to feeding their animals with stripped coconut frond and banana leaves. Fresh corn stalks are abundant during July and August, and corn stovers are fed to livestock in September (12–52% of the feed).

Corn is a common crop in all three villages. It is intercropped with rice and coconut, and, in sugarcane farms, a small portion of the field is usually cultivated with the crop. This explains the value and common use of corn by-products as feed in the three villages studied.

Among the three study areas, the farmers from Santa Teresita did exceptionally well; they raised more and better animals than the farmers in the other two areas. This could be attributed to abundant sugarcane tops over a long period (November–May) in the area, which enabled farmers to support their animals even during dry months. Sugarcane tops constituted 43–78% of the feed during milling season. Because the farmers' income from the principal crop is received at one time — harvest — the profit derived from raising three or more head of cattle serves as a buffer during the lean months. Cattle fattening is regarded as a business enterprise as reflected by the fast turnover rate of animals.

Farmers in all barrios take advantage of the source of protein found in the leguminous plant species, particularly *Centrosema* and *A. indica*, that are associated with their crops. Leucaena is extensively used in one of the villages (Pacifico).

Leucaena Forage Management in India

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Leucaena has been introduced as a fodder crop on unproductive land in India to support a dairy farming program. At the same time, research has been undertaken on environmental and management factors that affect forage yields from leucaena, and some attempts have been made to standardize management practices. Temperature, intensity and duration of solar radiation, rainfall, and soil conditions are the environmental factors that affect yields. Leucaena grows well at high temperatures with well distributed annual rainfall of, or irrigation to, 1500 mm. The crop responds well to phosphorus, calcium, and nitrogen. Growth is stunted during the winter months. In India, Salvador and Peru types as well as Cunningham have replaced Hawaiian type varieties for forage production.

Leucaena a été introduit comme plante fourragère dans les terres improductives de l'Inde dans le cadre d'un programme visant à développer l'industrie laitière. Simultanement, on entreprenait l'étude des facteurs relatifs à l'environnement et aux pratiques culturales susceptibles d'affecter les rendements en fourrage de la plante, et quelques tentatives ont été faites pour normaliser ces pratiques. La température, l'intensité et la durée de la radiation solaire, la pluviosité, la nature des sols sont les facteurs environnementaux qui affectent le plus les rendements. Leucaena supporte bien les températures élevées accompagnées d'une bonne répartition des pluies annuelles ou, à défaut, d'irrigation pouvant atteindre 150 cm. La récolte réagit favorablement au calcium, au phosphore et à l'azote. La croissance est interrompue durant les mois d'hiver. En Inde, les variétés Salvador et Peru, ainsi que Cunningham ont remplacé celles du type hawaïen pour la production du fourrage.

La leucaena ha sido introducida como cultivo forrajero en tierras improductivas de India para apoyar un programa agrícola y lechero. Al mismo tiempo, se ha emprendido investigacion sobre factores ambientales y de manejo que afectan los rendimientos del forraje de leucaena, y se han realizado intentos por normalizar las practicas de manejo. La temperatura, la intensidad y duracion de la radiacion solar, la pluviosidad y las condiciones edaficas son los factores ambientales que afectan el rendimiento. La leucaena crece bien a altas temperaturas con pluviosidad anual bien distribuida, o irrigacion, de 1500 mm. El cultivo responde bien al fosforo, calcio y nitrogeno. El crecimiento se detiene durante los meses de invierno. Los tipos Salvador y Peru asi como el Cunningham han reemplazado en India a las variedades Hawaii en la produccion de forraje.

I work for a voluntary agency, called the Bharatiya Agro-Industries Foundation (BAIF), which is engaged in rural development in India through the upgrading of local, unproductive cattle for milk production. It has been shown by BAIF that a family maintaining only two cross-bred cows can earn about US$ 400 year, which is twice the income of the average family just on the borderline of poverty. As the major expense in dairy farming is for feed, BAIF decided to promote the production of nutrient-rich leucaena forage, on marginal and waste lands where nothing was being grown.

In 1971–72, my colleagues and I at BAIF collected the seeds of Hawaiian types of leucaena from Australia, and after the University of Hawaii reported the growth rates of its new introduction — the Hawaiian giant — we began promoting leucaena not only for fodder but also for wood production. During the last year, BAIF has distributed 25 t of K8 seeds to agencies and farmers throughout India.

We conducted several agronomic studies to standardize the cultivation practices to maximize forage production. In this paper, I highlight the management practices recommended by BAIF, while reviewing the work done in different leucaena-growing areas.

In a country like India, where about 80% of the cropping area is dependent on rainfall, most farmers are unable to break even. The erratic monsoons and increases in the cost of inputs have meant that more and more marginal land is no longer being cultivated. In such areas, leucaena can be grown profitably for forage and wood for fuel and pulp.

A study conducted by a government of India planning commission indicated that the only

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asset that was equally distributed among the rich and the poor classes was the more than 200 million cattle. Unfortunately, these cows have the world's lowest average milk yield, although the introduction of cross-breeding techniques could increase milk yield substantially, especially if coupled with the use of leucaena for forage production. The management practices for leucaena forage production depend on whether cultivation is to be large or small scale and are secondary in importance to environmental conditions.

Environmental Factors

Temperature, solar radiation, rainfall, and soil conditions affect the adaptability and the rate of growth of leucaena, which, in turn, affect the forage yield. Leucaena thrives best at high temperatures once it has become established (Savory 1979). The variation in its performance at different altitudes and latitudes is also related to the variation in temperature. It grows well at 1500 m along the equator in Papua New Guinea (Hill 1971b) and Indonesia (Dijkman 1950), whereas its growth is restricted, even at 700 m, in the Philippines (Farinas 1951) and at 500 m in Hawaii (NAS 1977).

The central experimental station of BAIF at Urulikanchan is 560 m above sea level at 18.5 N. The temperature ranges from 0 C in winter to 41 C in summer. Under these conditions, leucaena grows extremely well and is grown even further north (up to 30 N), where the winter is severe for about 2 months when the average minimum and maximum temperatures remain at 3–5 C and 22–25 C, respectively. In such areas, leucaena plants do not put on any new growth during the winter months. There are no specific studies that separate the effect of solar radiation from that of temperature, but Dijkman (1950) reported that the rate of growth of leucaena is optimum under full sun. Shading increases plant height but reduces root growth as well as forage yield (Egara and Jones 1977). Seasonal effects on leucaena have been studied by several researchers. Guevarra (1976) observed that the factors causing seasonal variation are the intensity and duration of solar radiation and day and night temperatures. Kinch and Ripperton (1962), while growing Hawaiian-type leucaena for forage production, recorded a weekly stem growth of 20–21.5 cm in summer and only 4–5 cm in winter under adequate soil-moisture conditions. The slow growth affected the average daily yield of forage as well as the harvesting interval (Kinch and Ripperton 1962, figure 5). In Malawi, Savory (1979) observed the effects of seasonal variation on the branch production of Peru-type leucaena. Ferraris (1979) reported that temperature and radiation have a positive correlation with yield and a negative correlation with nitrogen content in the foliage.

Leucaena can be grown anywhere in the tropics and subtropics where annual rainfall ranges from 500 mm to 3000 mm and where soil conditions are favourable. Harvesting a good forage yield, however, requires a well-distributed average rainfall of 100–125 mm/month. Leucaena is tolerant to drought but cannot yield forage under continuous drought stress. It can be grown in heavy rainfall areas as well, provided there is adequate drainage. Supplementary irrigation is beneficial for leucaena being grown under dry conditions. Moisture stress affects the leaf and stem production of leucaena. Under drought conditions, there is reduction in the size and number of leaflets as well as the number of pinnules. Leaves rapidly start wilting and dropping. Drought affects the number of stems as well as the rate of stem elongation (Takahashi and Ripperton 1949).

In Hawaii, Kinch and Ripperton (1962) estimated a water requirement of 54 mm t dry matter and a total 1100 mm rainfall or equivalent irrigation to produce 50 t dry matter/ha annually. They observed a positive correlation between the moisture supply and the forage yield, but excessive irrigation is not beneficial. In a study conducted by Takahashi and Ripper-

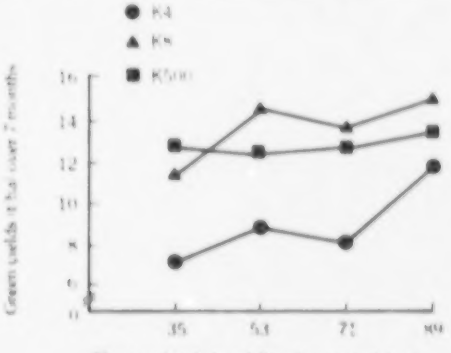

Fig 1 Effect of different levels of soil moisture on leucaena forage yield at 1 year

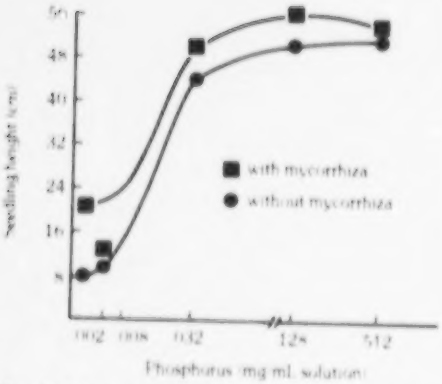

Fig 2. Effect of different levels of phosphorus on the growth of leucaena (K8) 3-month-old seedlings

ton (1949), there was no significant difference in the forage yield from leucaena receiving supplementary irrigation at intervals of 35 and 10 days. At low levels of moisture, James Brewbaker and I (unpublished data) found that K8 and K500 yielded better than K4 (Fig. 1).

In areas where the rainfall is below 700–800 mm spread only during the 4–5 monsoon months, forage production is restricted to these months. In such areas, irrigation is essential for good forage yield throughout the year. In the absence of irrigation, leucaena plantations should be established for wood production. It is a hardy plant and can withstand long dry seasons (5–7 months) from the 2nd year of its establishment. It can grow on almost any type of soil but cannot tolerate pH lower than 5 or waterlogging. The presence of *Rhizobium* and mycorrhiza in the soil is beneficial.

At Urulikanchan, K8 grew 8 m high in 2 years on soil only 12–15 cm deep on basalt rock.

Two strains of *Rhizobium*, CB 81 and NGR8, are widely used for acidic and alkaline soils respectively. Based on a study conducted by Relwani and others (1981, unpublished data), BAIF is promoting the use of mixed inoculant containing CB 81 and NGR8 strains.

In an experiment conducted at Hawaii, of five species of mycorrhiza, *Glomus fasciculatus*[2] alone was beneficial to leucaena. Mycorrhiza was helpful in increasing the uptake of phosphorus, particularly in the soils

[2] Other species tried were *G. monoporus*, *G. mosseae*, *G. etunicatus*, and *A. trapii*.

Leucaena is known for its characteristically deep roots; planting in acid, waterlogged, or nutrient-poor soils inhibits root growth and penetration, leading to windthrow in dry periods.

with low-P levels, and the phosphorus, in turn, improved root nodulation and increased plant height and dry-matter yield (Fig. 2, N. Hegde et al. 1982, unpublished data). Phosphorus seems to be a critical nutrient for leucaena. On

A schedule for harvesting should be based on height and stem diameter.

soils with low P, leucaena may be impossible to grow without the application of fertilizer.

In a related experiment, leucaena seeds were sown in pots containing soil with five different levels of phosphorus — 0.002, 0.008, 0.032, 0.128, and 0.512 mg mL solution — and were provided with adequate amounts of N, K, and Ca. After 3 months, the seedlings at the first two levels of P had only grown 8 and 20 cm high, respectively, whereas the plants grown at 0.032 mg P had grown 45 cm tall. A similar trend was observed in root growth and total dry-matter production (Fig. 2). In Hawaii, in addition to P, leucaena responds well to nitrogen and calcium (Takahashi and Ripperton 1949).

BAIF recommends the annual application of single superphosphate (50–100 kg/ha) for leucaena crops that are under intensive forage production.

Management Factors

For forage production, the Hawaiian-type leucaena has been replaced by Salvador, Peru types, and Cunningham cultivar in most areas. Among the Salvador types, K8, K28, and K67 are well known, and K8 has been used widely during the last decade. Among the Peru types, although there are several accessions including K3, K4, K6, K33, K59, K62, K77, K95, and K101 (Brewbaker et al. 1972), no one accession is preferred, and a comparison of their specific abilities and forage yields would be worthwhile.

In Australia, Cunningham yielded 27–49% higher than all the others, and the Salvador and Hawaiian types yielded significantly lower than the Peru type (Hutton and Bonner 1960; Hutton and Beattie 1976). However, in Malawi, there was no significant difference between forage yields from K8, Peru, and Cunningham (K500), although K8 was more vigorous than Peru, particularly during the dry season (Savory 1979). No yield differences in these three accessions were found in Fiji either (Partridge and Ranacou 1973). In a trial conducted in Hawaii, K8 yielded marginally more forage than Cunningham, but the quality was lower, the Cunningham cultivar having a higher leafy fraction in the foliage. For intensive forage production under short intervals of harvesting, Cunningham seems to be the ideal because of its high leafy fraction and wide-angle branching, the latter of which allows new shoots to spread wide and cover the ground much earlier than is possible with K8 or Peru. The advantages of early groundcover are:

- Good utilization of solar energy;
- Maximum exposure of the leafy area to sunlight, particularly the lower leaves;
- Prevention of soil-moisture evaporation; and
- Good weed control.

All these factors combine to increase forage yield. In K8, the branch angle is narrow, whereas the growth rate is slow in Peru (N. Hegde and J. Brewbaker 1982, unpublished observations).

Savory (1979) reported a negative correlation between the plant density and the number of branches per plant as well as the forage yield per branch. At high densities, however, the losses in forage yields from individual plants are offset by the increased number of plants, and the total yield for both Hawaiian and Salvador types increased with increases in density (Guevarra 1976). A plant population of 100 000–150 000 ha may be the ideal for forage production. Populations higher than 130 000 ha are effective in controlling weeds. The yields actually show a positive correlation with plant density up to 220 000 plants/ha (Savory 1979), but the benefits of increasing the population to more than 150 000 plants/ha

are marginal. While considering the plant population, one should also consider the spacing between the rows. Savory (1979) obtained higher yields from a row spacing of 60 cm than from 100 cm, although the plant density was constant.

Under intensive management practices, BAIF recommends a row spacing of 50 - 75 cm and a plant population of 100 000 - 120 000 seedlings/ha.

Two factors influence the decision on when to harvest the forage:

- Morphology of the cultivar or the type of leucaena; and
- The system of farming.

In Hawaiian types, several branches emerge at the crown and creep on the ground. If these branches are pruned, new shoots sprout and grow vigorously. Therefore, it is beneficial to harvest the Hawaiian type at low heights, particularly during the early stages. Harvesting high above the ground results in new shoots mainly on the main stem. The new shoots will be few and poor in vigour.

In the Salvador type, as there is no significant branching at the crown, only the axillary buds on the main stem will have to sprout to produce the new branches. At harvest, this type should be taller than the Hawaiian type so that several axillary buds are retained. This is also true for the Peru types, although they may have more than one main stem. Takahashi and Ripperton (1949), studying the Hawaiian type, obtained the highest yield (50.9 t/ha) of green forage when the leucaena was cut at 5 cm above the ground. At 38 cm and 76 cm, yields were 43.40 t/ha and 40.28 t/ha, respectively. The different requirements of the Salvador types are apparent from a study in which a uniform height (5 cm) was maintained for both Hawaiian and Salvador types: the former markedly outyielded the latter (Guevarra 1976). In a trial conducted in the Philippines, highest annual dry-matter yield (23.6 t/ha) was recorded when the plants were maintained at 3 m high and the leaves were plucked. Yield was maximized when 25% of the foliage was left on the plants (Mendoza et al. 1975).

In Hawaii, mechanized harvesting of the Hawaiian type was at 15 cm above ground (Kinch and Ripperton 1962), but the Peru and Salvador types should be harvested at 30 - 50 cm high under mechanized cultivation. In India, harvesting at 90 - 100 cm high produced good yields as well as minimizing the labour costs for weeding and manual harvesting (N. Hegde, unpublished data). The basal branches of the Hawaiian type should be pruned during the initial stages, at about 2 months after planting. Pruning promotes the growth of the main stem and is extremely important if one wants to maintain the cutting height at 90 - 100 cm.

Different criteria used in the past to determine the harvesting frequency were:

- The onset of flowering;
- The predetermined branch length at harvesting;
- The predetermined number of harvests/year;
- The twig diameter; and
- Yellowing of the basal leaves.

Onset of flowering cannot be used as a criterion for Salvador and Peru types, as they do not flower as frequently as the Hawaiian type throughout the year. Kinch and Ripperton (1962) had fixed the height at cutting at 1.0 - 1.2 m for Hawaiian types, which allowed 4-6 harvests/year. In Fiji, harvesting Peru types when the branches are 90 cm long permitted five harvests the 1st year and six harvests the 2nd year (Partridge and Ranacou 1973). Branch length can be a valid criterion, provided specific heights are considered for different types. In general, the Salvador type may be allowed to grow longer than the others, followed by Cunningham, Peru, and Hawaiian.

Savory (1979) reported that, in the Peru type, four harvests/year yield higher than three or six harvests. However, several researchers have reported that, although the increase in the interval increased the total dry-matter yield, the quality of the feed deteriorated because of the reduction in the nitrogen content of the foliage and the high proportion of inedible stems in the harvest (Takahashi and Ripperton 1949; Guevarra 1976; Sampet and Pattaro 1979). Guevarra (1976) and Ferraris (1979) found that harvesting at monthly intervals brought down the yield as well as the nutritive value; however, Sampet and Pattaro (1979) reported that frequent harvests (every 4 - 6 weeks) in Thailand reduced the woody dry-matter yield without affecting the forage dry-matter yield. In Papua New Guinea, under adequate moisture conditions, the crop was ready for harvest in 6 weeks during the summer months (Hill 1971b). Recommending harvesting every 8 weeks for

warmer lowland areas, Brewbaker et al. (1972) suggested that the erect strains be harvested more frequently than the shrubby strains.

One should fix a harvesting schedule, based on a fixed height and stem diameter at cutting. Stem colour is also an indicator: green stems are mostly palatable, whereas the older, gray or brown, stems are woody. Under adequate soil-moisture conditions, leucaena grows vigorously and produces thick (~10 mm) shoots that are green, soft, and palatable (unpublished observations). Hence, the combination of stem colour and diameter is a good criterion for scheduling the harvests. When the stems start turning gray from green is the right time for harvest.

In India, the growth rate of leucaena is much higher than that in Hawaii, and, at Urulikanchan, we can take eight cuts/year (based on 5 years' harvesting data) under irrigated conditions. The farmers are keen to harvest at shorter intervals so that they can feed their livestock green fodder regularly while maintaining a very small area for forage production. Study of the growth pattern of leucaena under the prevailing agroclimatic conditions is needed before harvesting schedules can be recommended for particular areas.

Effects of Leucaena Leaf Meal in Feed for Japanese Quail

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Toxicity of leucaena forage is a subject of much research. The problem has almost been solved for the ruminants but not for poultry. Although mimosine is the main toxin, tannin has been proposed as partially responsible for the poor performance of poultry fed leucaena. This possibility was studied in 10 day old Japanese quail fed leucaena containing different levels of mimosine and tannin for 4 weeks. Their progress, as measured by weight gain, feed conversion efficiency, and digestibility coefficient, was significantly below that of chicks fed control diets; the diet with the highest level of mimosine produced the lowest weight gains, whereas the adverse effects from the leucaena with the highest tannin were similar to those for the other diets with comparable mimosine contents.

La toxicité de Leucaena fait l'objet de nombreuses études. Le problème a été presque résolu en ce qui concerne les ruminants, mais non pour la volaille. Bien que la mimosine constitue la toxine principale, on a allégué que le tanin contribuait, pour sa part, aux piètres résultats obtenus de la volaille nourrie avec Leucaena. Cette possibilité a été étudiée sur des cailles japonaises âgées de 10 jours, et nourries durant 4 semaines avec du Leucaena contenant différentes teneurs de mimosine et de tanin. Leur développement, évalué d'après les gains de poids, la conversion alimentaire et le coefficient de digestibilité a été notoirement inférieur à celui des poussins recevant des régimes-témoins. La ration contenant la plus forte dose de mimosine a donné les gains pondéraux les plus faibles, et les effets défavorables de Leucaena ayant le plus fort contenu de tanin ont été identiques à ceux obtenus des autres régimes ayant une teneur en mimosine comparable.

La toxicidad del forraje de leucaena es un tema de mucha investigación. El problema ha sido casi solucionado para los rumiantes pero no para las aves. Aunque la mimosina es la principal toxina, el tanino ha sido propuesto como responsable parcial del mal desempeño de las aves alimentadas con leucaena. Esta posibilidad fue estudiada en codornices japonesas de 10 días de edad alimentadas con leucaena a diversos niveles de mimosina y tanino por 4 semanas. Su progreso —medido por la ganancia de peso, la eficiencia de conversión alimenticia, y el coeficiente de digestibilidad— fue significativamente más bajo que el de pollos con dietas de control; la dieta con el mayor nivel de mimosina produjo menores ganancias de peso, mientras que los efectos adversos de la leucaena con mayor contenido de tanino fueron similares a los de otras dietas con contenidos comparables de mimosina.

Padgett and Ivey (1959) and Wilson et al. (1961) have indicated that the Japanese quail (*Coturnix japonica*) is suitable for pilot studies on poultry because of its short life cycle and low feed requirements. The physiological systems of Japanese quail are similar to those of poultry.

Studies on leucaena-supplemented rations have shown promise for the crop's use in poultry feed, with increases in the weight of chicks (Dingayan and Fronda 1950) and improved egg colour (Sadoval 1954). Palafox (1948) recommended feeding poultry only 2–3 g fresh leaves/day, from age 14 days onward. Diets containing more than 10–15% leucaena have been shown to depress the growth and maturity of birds. Several researchers have reported mimosine as the cause of the poor growth and have found that ferrous sulfate reduces toxicity (Ross and Springhall 1963).

In an experiment conducted in Hawaii, Japanese quail receiving 20% leucaena showed depressed growth, poor feeding efficiency, undersized sex organs, delay in sexual maturity, and high mortality. However, the histological studies did not indicate any adverse effects of leucaena on the liver, spleen, intestine, or thyroid. When the ration containing 20% leucaena was supplemented with methionine (0.1%) and corn oil (6%), the birds showed significant improvement. Mimosine was traced in the excreta after ingestion of leucaena, although a major portion was metabolized (Thanjan 1967). Ross et al. (1980) reported a drop in egg production from the 7th day after quails started consuming a diet with 20% leucaena, whereas a group receiving 1% pure mimosine performed normally till 14 days. This study indicated toxicity

not only from mimosine but also from some other compounds present in leucaena.

D'Mello and Fraser (in press) reported the presence of 2.0–3.36% tannin in leucaena forage and suggested that tannin was responsible for toxicity. Tannins adversely affect the digestibility of the feed and utilization of the nutrients. A diet containing tannic acid depressed the growth of chicks, although the effects were reversed when chemicals, such as sodium carbonate and calcium hydroxide (at 0.022%), or nonionic polymers, such as polyvinyl pyrrolidone (PVP) or Tween 80, were added. These chemicals bind tannic acid and prevent it from precipitating proteins (Rayudu et al. 1970).

Recently, we conducted a feeding trial with Japanese quail at the University of Hawaii for 4 weeks, starting with 10-day-old birds, and using a randomized, complete block design. Six different dietary treatments (Table 1) were evaluated, with three replications, and each treatment unit had seven birds. The birds had free access to feed and water.

The quail of each unit were separated according to sex and collectively weighed at the end of each week when other measurements such as feed consumption, water intake, weight of the fecal matter were also recorded.

At the end of the trial, a few birds receiving the positive-control and the K8 tender-leaf-meal diets were killed, and the thyroid, liver, kidney, and sexual organs examined.

Mimosine in the feed was analyzed by the colorimetric method (Meggarity 1978), which records the total for mimosine and DHP content. Tannin analysis of the leaf meals was carried out by the Vanillin–HCl method and expressed in percent catechin equivalent.

Results

At the end of the feeding trial, both female and male quail on the K8 tender-leaf meal

Table 1. Composition of six rations fed to Japanese quail for 4 weeks.[a]

	Diet					
	Positive control	Negative control (alm)	K8 tlm	K8 mlm	K156 lm	K8 mlm + PVP
Ingredients (%)						
Choline	0.160	0.160	0.160	0.160	0.160	0.158
$CaCO_3$	3.000	3.000	3.000	3.000	3.000	2.970
Ext. phosphorus	3.500	3.500	3.500	3.500	3.500	3.465
Methionine	0.100	0.100	0.100	0.100	0.100	0.099
Meat, bone meal	5.000	5.000	5.000	5.000	5.000	4.950
Tuna meal	5.000	5.000	5.000	5.000	5.000	4.950
Salt	0.300	0.300	0.300	0.300	0.300	0.297
Vitamin mix	0.038	0.038	0.038	0.038	0.038	0.038
Corn	39.5	31.1	32.8	32.2	31.9	31.878
Soy meal	37.4	33.8	32.1	32.7	33.0	32.373
Tallow	0.69	3.0	2.76	2.84	2.97	2.812
Cellulose	2.31	—	0.24	0.16	0.03	0.158
Alfalfa meal	3.00	15.00	—	—	—	—
Leucaena meal	—	—	15.00	15.00	15.00	14.850
Polyvinyl pyrrolidone (PVP)	—	—	—	—	—	1.00
Nutritive value						
Crude protein (%)	28.83	29.27	29.63	29.26	29.37	29.41
Ether extract (%)	3.78	6.30	5.90	6.78	6.56	6.55
Ash (%)	12.30	13.08	12.20	12.83	13.01	12.70
Dry matter (%)	89.06	89.30	89.43	89.93	89.74	89.80
Total energy[b] (cal/kg)	2600.00	2600.00	2600.00	2600.00	2600.00	2574.00
Mimosine (%)	—	—	1.10	0.44	0.30	0.43
Tannin (% catechin equivalent)	0.0189	0.0945	0.225	0.645	0.1725	0.639

[a] tlm = tender-leaf meal, mlm = mature leaf meal, lm = leaf meal, and alm = alfalfa leaf meal.
[b] Total energy was computed, based on the feeding values.

Table 2. Growth of 10-day-old Japanese quail fed leucaena for 4 weeks.*

	Weight gain (g/bird)		Average feed-conversion efficiency (g/g weight gain)	Average digestibility coefficient of feed	Average water consumption (mL/bird)
	Female	Male			
Positive control	106.7a	86.5a	3.54a	0.6320a	738
Negative control	101.3ab	97.7a	3.63a	0.5609c	819
K8 tlm	60.3c	66.6c	3.93b	0.5720bc	659
K8 mlm	81.6b	77.3b	4.04b	0.5704bc	735
K156 lm	83.2b	87.2b	4.30c	0.5735bc	860
K8 mlm + PVP	83.5b	77.7b	4.41c	0.5970b	904

* In vertical columns, figures followed by the same letters do not differ significantly ($P > 0.05$).

Table 3. Nitrogen and mimosine contents in fecal matter of Japanese quail maintained on six different diets.

	Nitrogen (%)		Mimosine (%)	
	Week 2	Week 4	Week 2	Week 4
Positive control	4.70	6.73	—	—
Negative control	3.89	5.80	—	—
K8 tlm	5.47	6.52	1.37	1.43
K8 mlm	4.49	6.74	0.77	0.67
K156 lm	5.77	7.32	0.45	0.35
K8 mlm + PVP	5.51	6.16	0.77	0.60

showed extremely poor weight gain, which was highly significant (Table 2). Among the other treatments, birds maintained on both the positive control and negative control diets had significantly higher weight gains than all the other groups among which there was no significant difference. This trend had been set within 1 week of the initiation of the experiment.

Female birds were heavier than the males in all except two of the treatments. Birds receiving the K8 tender-leaf meal were very small, with thin, loose skin. None of the groups lost their feathers.

The average feed-conversion efficiency was high for both the positive and negative control diets, intermediate for both the K8 tender- and mature-leaf diets, and low for the K156 and K8 + PVP diets, the differences between the three groups being significant. Feed-conversion efficiency was high in the 1st week and progressively declined as the birds gained weight.

There was a small wastage of feed for all four groups receiving leucaena leaf meal, which was noticeable in the form of green dust in the collection trays. Such wastage was high in the K156 units. In the K8 + PVP treatment units, the birds were often found with a thick coating of feed hardened on their beaks. In some cases, they needed help to shed these feed coats.

The positive control had the highest digestibility coefficient, which was significantly ($P < 0.05$) higher than all the others. The negative control diet had the lowest, although it did not differ significantly from the leucaena leaf-meal diets. The quail on the K8 + PVP diet consumed the most water, but the difference was not significant. Nitrogen contents were highest in the fecal samples of the K156 group and lowest in the negative control (Table 3).

The fecal samples of the K8 tender-leaf-meal group had the highest mimosine content (Table 3). Electrophoresis indicated that almost 75% of the total content was in the form of mimosine, with the rest being DHP. When the thyroid, liver, kidney, and sexual organs of the control and leucaena-fed birds were examined, a general correlation was observed between size of organs and body weight, although there was no visible difference in the size of the thyroids. Several yolks, ranging from 2 mm to 10 mm, were found in the females of the control treatments, whereas no yolks were visible in the birds fed K8 tender-leaf meal.

Discussion

The nutritive value of all the treatments in terms of protein, energy, fat, and ash was

almost equal. The variation among these feeds was in their mimosine and tannin contents. K8 tender-leaf meal, which was responsible for poorest weight gain, had the highest mimosine content (1.10%) and low tannin content (0.225%). The other leucaena treatments had mimosine concentrations ranging from 0.30% to 0.44%, whereas they varied widely in their tannin content. Therefore, the poor performance in the group consuming leucaena leaf meal could be attributed to the toxicity of mimosine (Springhall and Ross 1965a; Thanjan 1967; Labadan 1969; D'Mello and Thomas 1978).

The mimosine content of the fecal samples was proportional to the mimosine present in the feed. As a major portion of the mimosine was excreted in the form of mimosine (not DHP), the thyroids were not affected. Mimosine suppressed the growth of the quails and, as a result, may delay maturity. The specific role of mimosine in suppressing growth is not known.

Between the K8 mature-leaf meal diet and the K156 diet, there was no statistical difference in growth rate, digestibility coefficient, or N contents of the fecal samples, although the tannin contents were 0.6450% and 0.1725% respectively. Tannin affects the digestibility of the feed by precipitating proteins. One might expect, therefore, that high tannin contents would cause large amounts of nitrogen to be excreted in the feces and be accompanied by protein deficiencies in the birds. However, in this trial, there was no evidence to confirm the suppression of growth by tannin, as the N contents in the fecal samples of the high-tannin diet group (K8) were lower than those for the low-tannin group (K156).

Feed-conversion efficiency in this trial was probably affected by the wastage of feed. It may have been advisable to use small pellets of leaf meal instead of 20 mesh powder.

Use of PVP as suggested by Rayudu et al. (1970) was effective in binding the external source of tannin, but it is doubtful about its role internally, before the tannin–protein interaction. The presence of PVP caused the formation of a hard coat of feed around the beaks of the birds, which in turn might have affected the feed efficiency.

Leucaena Research at the Indian Grassland and Fodder Research Institute (IGFRI)

P.S. Pathak and B.D. Patil *IGFRI, Jhansi, India*

At the Indian Grassland and Fodder Research Institute, studies on leucaena have been under way for more than a decade. They cover seedling growth and germination, establishment, effects of seasonal variation and other environmental conditions on the growth of the plant, etc. Breeding and selection are being carried out as are investigations into the uses of leucaena as pasture, fuelwood, and green manure. Some of the findings of the studies are reported in this paper.

L'Institut de recherches sur les herbages et le fourrage de l'Inde (IGFRI) poursuit depuis plus de dix ans des études sur Leucaena *portant sur la germination et le développement des jeunes semis, leur implantation, les effets des variations saisonnières et autres facteurs écologiques sur la croissance des plants, etc. Les travaux de reproduction et de sélection visent surtout à explorer les divers rôles que* Leucaena *pourrait remplir comme plante à pâturer, comme engrais vert et comme bois de chauffage. Cet exposé décrit certains résultats de ces diverses études.*

En el Instituto Hindú de Investigaciones en Pastos y Forrajes (IGFRI) se han realizado estudios sobre leucaena por más de una década. Estos comprenden crecimiento y germinación de las plántulas, establecimiento, efectos de la variación estacional y otras condiciones ambientales sobre el crecimiento de la planta, etc. El mejoramiento y la selección son objeto de investigación, así como los usos de la leucaena como forraje, combustible y abono verde. En este trabajo se reseñan hallazgos de los estudios.

The Indian Grassland and Fodder Research Institute, Jhansi, has studied different systems of utilization of leucaena since 1970. The research at IGFRI has focused on the potential of leucaena for forage during periods of scarcity and for firewood in rural areas.

Jhansi is situated at 25.27 N and 78.37 E at an altitude of 275 m. The climate is dry, tropical, with an annual rainfall of 900 - 1000 mm, 90% of which falls between June and September. Winter showers are light and unreliable and droughts recur even during the monsoon season. Mean maximum and minimum temperatures are 32.9 C and 17.4 C with temperatures as high as 45.7 C and as low as 3 C. There are three seasons — the monsoon (hot and wet), winter (cold and dry), and summer (hot and dry).

Soils in the experimental areas are red alfisols (gravelly to sandy loam) with high porosity and drainage, often having rock basements of gneisses and schists at variable depths. Rooting is thus variable. There are also pockets of black vertisols.

Collection of Germ Plasm

In 1970 - 71, naturalized types of leucaena were collected throughout the country. Australia provided Peru and Cunningham in 1973 and, in 1982, another 22 introductions, including *Leucaena diversifolia*, *L. esculenta*, *L. pulverulenta*, and *L. collinsii*. In 1976, 14 collections were received from the Philippines and 6 from Malawi, and, in 1981, J.L. Brewbaker sent 9 collections including *L. diversifolia*. The naturalized varieties occurring in India are the common type with shrubby growth and low yields but with significant interpopulation differences.

Seed Germination

Interpopulation variation in seed vigour and polymorphism is significant among varieties. There are positive correlations between size index and seed weight, shape index and seed weight, length and seed weight, and length and thickness. The weight per seed ranges between 10 mg and 70 mg, with a trend toward heavier seeds in southern latitudes (Pathak et al. 1974). Seeds ripening during the dry months are smaller and lighter than those in the wet months.

Seeds need scarification for optimum germination. IGFRI findings are that soaking 10 min in concentrated sulfuric acid produces the best results and alternating temperature between 20 C and 32 C gives maximum germination (Pathak et al. 1974). Another interesting finding was that seeds stored for 3 years germinated well and had lower scarification requirements than fresh seeds.

Under field conditions, hot water (80 C) treatment of seeds followed by cooling of the water and swelling of the seeds overnight gives more than 80% germination.

Seedling Growth

Results of various studies on seedling establishment showed that seeds sown 2 -4 cm deep recorded better growth than those sown at shallower depths or those broadcast on the surface. Maximum growth of seedlings was obtained when 20 kg nitrogen, 40 kg phosphorus, and 20 kg potash were applied at planting.

A positive correlation has been found between seed weight and seedling vigour and other parameters (Pathak et al. 1981). In a trial involving common, Peru, and K28, field emergence was highest in common, but seedling growth was the best in K28 followed by Peru.

In all varieties, total dry weight was greater for inoculated seedlings than for uninoculated treatments. Nodules were larger and heavier in K28 (75 mg/plant) than in Cunningham (41 mg/plant). M.R. Pahwa and B.D. Patel (unpublished manuscript) found that composite inoculum gave better nodulation than did a single rhizobium strain.

Field Establishment

Seedlings planted from plastic bags usually gave better field establishment than bare-rooted seedlings direct from the nursery. Survival of Peru types was much higher on black soils than on the red gravelly murram soils, and establishment on natural rangelands of red murram soil was better in furrows than on ridges. Direct seeding gave poor establishment because of weed competition.

Application of phosphorus (40 kg/ha) and nitrogen and potash (each, 20 kg/ha) at planting gave good establishment and growth. Control of weeds especially in the rainy season was essential. Four-month-old seedlings, 1 m high, gave a better establishment than did smaller and younger seedlings.

Selection and Breeding

Collections from various regions are screened at IGFRI for wood and forage production and also for their general agroforestry potential. Forage types need to be short, multibranched, and leafy, with high drought tolerance. Types to be planted with a companion crop need to have a canopy structure that allows light penetration.

In the breeding program at IGFRI, most characters had high heritability except leaflet length and seed yield.

Effects of Sunlight

Leaf dry matter of leucaena varieties varied from 32% to 37%, the maximum being in Peru types. Also, Peru types contained the most chlorophyll b, but common types had the most carotene and total chlorophyll. Total chlorophyll was higher in basal leaves and decreased toward the apical region in an inverse relationship with light penetration. Peru types showed a maximum chlorophyll carotenoid ratio in the basal parts. Chlorophyll b is more susceptible to photo-oxidation and is affected by self-shading and branching pattern.

Light conditions greatly affect seedling growth, but, in summer, when temperatures may be greater than 46 C and light at a maximum, growth is reduced (Table 1).

Table 1. Seedling growth performance (90 days) under different light proportions.

	Light conditions (temperature)*		
Growth attributes	100% (35.4 C)	45% (32.7 C)	20% (28.3 C)
Root length (cm)	47.2	30.3	11.2
Shoot length (cm)	31.5	72.3	23.0
Root dry weight (g)	1.29	0.97	0.10
Shoot dry weight (g)	2.11	4.33	0.50
Branching initiated (days)	60	67	—
Nodulation started (days)	67	54	90
Nodules/plant	66	50	3
Size of nodules (mm)	1.3	1.57	0.42

* Diurnal averages for temperatures.

Table 2. Growth increment[a] during seasons[b] of three varieties of *L. leucocephala*.

Variety	Rainy season		Winter		Summer	
	Height (cm)	Diameter (cm)	Height (cm)	Diameter (cm)	Height (cm)	Diameter (cm)
Hawaiian (common)	55.0	0.87	0.0	0.05	32.0	0.0
Peru	116.0	3.86	32.5	1.11	44.0	0.6
Salvador	196.0	4.72	88.0	2.35	48.0	0.57

[a] Means from 10 trees.
[b] Average maximum and minimum temperatures for the rainy season, winter, and summer were 33.9 C, 26.5 C, 26.4 C, 9.02 C, and 40.9 C, 21.8 C, respectively. Relative humidity was 69.6%, 71.2%, and 45.2%.

Table 3. Forage production (dry kg/m) in different harvests at three heights in hedges from common leucaena.[a]

Cutting height (m)	September	November	February	April	July
1.0	3.87	0.61	0.29	1.58	2.50
0.6	2.32	0.46	0.11	1.63	1.83
0.3	1.09	0.10	0.05	0.63	1.70

[a] Means of 10 replications.

Aboveground growth of seedlings was best at 45% light; seedling emergence was also best at this light intensity. Nodulation was earliest at 45% light, with fewer and larger nodules than at 100% light.

Seasonal Variation

Provenance trials with 30 collections of three varieties — common, Peru, and Salvador — were studied monthly for plant height and basal stem diameter (Table 2).

The best growth in all varieties is in the rainy season. Of the varieties tested at IGFRI, Salvador giant gave the best growth in all three seasons. Common gave the lowest growth, especially in the winter.

Effect of Maleic Hydrazide

Effect of foliar applications of maleic hydrazide (MH) to common, Peru, and Salvador varieties was studied in pot culture. MH is a powerful growth inhibitor and caused significant shoot retardation, with the production of dark green and thick leaves. MH at 500 ppm accelerated flowering and pod formation and maturation, but 1000 ppm delayed these. At 500 ppm, MH increased seed yield by increasing pod number and length and seed weight compared with the control. These findings show that MH could be useful for facilitating seed production in tall, woody types of leucaena.

Pasture and Forage Production

Common leucaena was severely attacked by termites when introduced into degraded pastures on red, gravelly soils in India. Peru was more resistant and survived. Leucaena was interplanted in rows with the grasses *Setaria anceps*, *Chrysopogon fulvus*, *Cenchrus ciliaris*, and *Heteropogon contortus*. Maximum leucaena establishment was in association with *C. fulvus* and the minimum with *C. ciliaris* (Pathak et al. 1974). In subsequent years, the maximum height, diameter, and forage production in leucaena were obtained in association with *H. contortus*.

Forage production from single-row hedges of common type leucaena around crop fields was also studied at IGFRI. Cutting was at different heights every 40–50 days (Table 3); it was found that a 1-m cutting height gives the highest annual forage yield.

Pathak et al. (1980) also studied common leucaena's forage production, using densities of 4, 3, and 1.5 plants/m^2; cutting heights of 10, 20, and 30 cm; and intervals of 40, 60, and 120 days under rainfed conditions during 1972–75 (Table 4). The highest plant density (4 plants/m^2) gave the highest forage production, and cutting height of 30 cm gave the best yields. Cutting interval did not significantly affect yields so cutting every 40 days would be the most profitable.

Forage production is markedly influenced by

Table 4. Effect of population density, cutting intensity, and interval on dry forage production (t/ha) of common leucaena.

	1972–73	1973–74	1974–75
Cutting interval (days)			
40	5.56	3.02	1.80
60	6.03	2.29	1.59
120	5.13	3.74	1.55
Plant density (plants/m²)			
4	8.78	4.93	2.43
3	4.57	2.71	1.64
1.5	3.37	1.42	0.88
Cutting height (cm)			
10	5.36	2.87	1.63
20	5.30	2.75	1.55
30	6.06	3.43	1.78

Table 5. Production of forage (dry t/ha) from different leucaena collections and varieties.

Provenances (source)	1977	1978	1979
India-Terai (Uttar Pradesh)	13.92	12.90	10.30
India Siwalik (Uttar Pradesh)	22.75	20.71	14.82
India Gangetic Plain (Uttar Pradesh)	24.13	24.83	20.10
India Vindhyan Range (Uttar Pradesh)	16.08	16.00	11.35
India Central India (Maharashtra)	15.71	13.71	12.32
India South India (Tamil Nadu)	8.74	7.83	6.25
Peru (Australia)	18.19	17.13	13.32
Cunningham (Australia)	32.92	25.04	21.35

the collection or variety (Table 5). In a study of eight accessions, sown at a density of 66 600 plants/ha with a basal application of nitrogen (30 kg/ha) and phosphorus (60 kg/ha) and harvested at 60-day intervals (30 cm high), the common type from the Gangetic Plain (Varanasi, Uttar Pradesh) gave an annual average yield of 23.02 t/ha, second only to Cunningham, the highest yielder.

Nutritive value of common-type forage was evaluated by Upadhyay et al. (1974) after 130 days' growth. The chemical composition was crude protein 21.45%, ether extract 6.54%, crude fibre 14.25%, ash 4.28%, calcium 2.70%, and phosphorus 0.17%. The results indicated high dry-matter content (34.26%) and crude protein; the nitrogen-free extract was 49.48%.

Barbari bucks, with an average body weight of 19 kg, fed green leucaena forage consumed, on average, 2.16 kg dry matter/100 kg body weight. The animal whose intake was maximum (2.76 kg) showed symptoms of alopecia in the last week of the experimental period. Digestibility coefficient of dry matter, crude protein, ether extract, crude fibre, and N-free extract was 71%, 78%, 47%, 57%, and 81%, respectively. All animals showed positive nitrogen and calcium balance, with only one animal of four showing phosphorus deficiency. Studies of the feeding value of leucaena in the form of silage, leaf meal, etc. are being carried out by the animal science branch of the Institute.

Agroforestry

Studies were made of the value of leucaena as green manure on red, gravelly murram soils. The leucaena plantings (40 000 plants/ha) were of different durations and were followed by a cereal fodder crop (Table 6).

Compared with the control plots, 30 kg N/ha gave a 36% increase in the yield of the first crop but no increase in the successive crop. However, with increasing periods under leucaena plantings, there were increasing levels of improvement in the first cereal fodder crop and also in the second crop. The leucaena leaf litter improved yields by as much as 150% for the first crop and 84% for the second crop when soil fertility was allowed to regenerate under leucaena plantings for 2 years.

Biomass Production

Pathak et al. studied the aerial biomass production from roadside plantations of Cun-

Table 6. Crop-yield improvement (% over control plots) after different durations of leucaena plantation

Treatment	Crop-yield improvement (%)	
	1st crop	Successive crop
30 kg N/ha	36.0	00.0
Months under *leucaena* plantation		
3	95.0	00.0
6	32.0	27.0
12	51.0	16.3
15	89.0	50.0
18	100.0	100.0
24	154.4	83.8

Table 7. Volume and weight of fuelwood produced by different varieties (Pathak and Patil 1981)

	2 years				2.5 years			
	Volume (m^3/ha)		Weight (t/ha)		Volume (m^3/ha)		Weight (t/ha)	
	Rate	Total	Rate	Total	Rate	Total	Rate	Total
El Salvador	22.25	44.50	20.56	41.11	70.10	175.25	31.62	79.04
Peru	4.98	9.96	3.28	6.57	20.59	51.47	14.57	36.42
Cunningham	8.51	17.02	5.30	10.60	15.34	38.35	7.41	18.53
K8	9.86	19.72	7.98	15.96	44.21	110.52	21.76	54.41
K28	21.20	42.40	14.85	29.71	39.98	99.96	22.74	56.84

ningham at 2-m spacings. Production was 5.9 kg/tree and 23.9 kg/tree at 3 and 4 years, respectively, with the mean annual increment being 1.98 kg/tree and 5.97 kg/tree. Thus, a farmer could annually derive 11 t firewood and 1 t (dry weight) forage from a km-long row of leucaena trees maintained for 3 years. The main function of the trees could be as a shelterbelt or as live fence.

On marginal, gravelly murram soils, K8 (5000 trees/ha) produced seed twice during the 2nd and 3rd years and, though progressively increasing biomass, experienced spurts of growth.

In trials on marginal soils, wood yields of five varieties were compared. The trees were planted 5000/ha, in both winter and summer, and harvested at 2 and 2.5 years (Table 7). El Salvador outyielded the other varieties, with Peru giving the lowest yields. The optimum planting time proved to be January, although irrigation was required during the dry months. Wood densities were similar for all except Peru, which exhibited markedly higher density (0.71 compared with 0.45, 0.48, 0.49, and 0.57 for El Salvador, Cunningham, K8, and K28, respectively).

Wood yields of eight varieties (two Peru and six Salvador types) were compared at two planting densities (5000 trees/ha, 10 000 trees/ha) for 2-year and 4-year rotations on marginal soils under moist conditions (Table 8). Total yields in one 4-year harvest were greater than those for two 2-year harvests, and yields were higher at 5000 trees/ha than at the higher density. Other experiments have confirmed that 5000 trees/ha is the optimum density for wood production under the conditions at Jhansi (Table 9).

Coppicing

After harvest, the production of coppice shoots is prolific; shoot initiation is affected by cutting height, cutting interval, and variety. In a trial to compare shoot production during different seasons and at different heights, common types planted along riverbanks were felled in March and January, at the base and at 15 and 30 cm high. The trees felled in March produced more shoots than those felled in January at all cutting heights. At 15 cm above ground, shoot production was twice that for trees cut at ground level, although not appreciably different from that at 30 cm high. For practical purposes, then, one could expect good shoot production from trees felled at

Table 8. Wood production (t/ha) of different varieties at two cycles and densities (average of four replications).

	5000 trees/ha			10000 trees/ha		
		2-year rotation			2-year rotation	
	4-year rotation	1st harvest	2nd harvest	4-year rotation	1st harvest	2nd harvest
Peru						
9	64.6	33.5	18.1	41.2	18.0	10.0
14	43.9	33.0	19.1	33.2	17.5	5.5
Salvador						
16	95.2	47.0	21.0	21.8	14.5	7.1
17	90.6	31.0	20.0	41.6	5.3	6.8
18	94.3	38.0	24.7	43.6	6.0	11.0
19	52.9	28.5	20.9	8.7[a]	29.0	6.8
21	94.2	29.0	15.8	20.5	10.0	3.2
24	121.2	59.0	30.7	62.4	15.0	6.0

[a] Plants affected by gummosis.

Table 9. Growth and production as influenced by plant density (average of five replications).

Plants/ha	DBH[a] (cm)	Height (m)	Biomass (kg/tree)			Production (t/ha)
			Bole	Branches	Leaves	
1000	8.0	8.2	8.5	4.5	1.2	14.2
5000	6.1	9.4	6.7	2.2	1.8	53.5
10000	4.7	5.3	2.05	0.7	0.1	28.5
40000	3.9	5.3	0.52	0.15	0.06	29.2

[a] DBH = diameter, breast height.

10 cm or slightly higher. Peru types produce fewer shoots than do the Salvador types under conditions found at Jhansi.

Other observations during IGFRI experiments are that:

- Clear felling is better than alternate-tree felling for coppice production because the canopy from unfelled trees reduces coppice growth;
- Shoot production is not affected by method of cutting;
- Protecting newly established (or newly coppiced) leucaena from grazing animals is essential; and
- Thinning at 6 and 9 months encourages good growth and shoot production.

A Research Priority

In India, a most important research priority is to develop measures to control the *Fusarium semitectum* causing gummosis. The species appears to thrive on certain cereals and grasses, and it is seriously threatening the economic potential of leucaena.

Some varieties in IGFRI trials have exhibited resistance to the fungus, and, thus, breeding holds promise for the development of resistant varieties. Although the fungus is serious only in particular areas of India, the potential threat is considerable.

Nitrogen-Fixing Fodder Trees in Nepal

Krishnakumar Panday *Federal Institute of Technology, Zurich, Switzerland*

The forests in Nepal have been seriously depleted by overuse for forage purposes, and, still, I estimate a fodder deficit of about 20% in the country. Fodder trees are the only green forage during the dry winters in most of the country, and Nepal has many varieties of fodder trees, with about a dozen being nitrogen-fixing species. Leucaena leucocephala has been introduced recently but has not yet been accepted by local farmers. There have been some growth trials by development projects, and the species seems to be well adapted to local conditions.

Les forêts du Népal ont été fortement dépeuplées par l'usage abusif qu'on en a fait comme source de fourrage, et la production fourragère est aujourd'hui d'environ 20 % inférieure aux besoins nationaux. Presque partout, au pays, les arbres constituent l'unique source de fourrage vert qui subsiste pendant les hivers secs, et le Népal possède de nombreuses variétés d'arbres fourragers dont une douzaine d'espèces peuvent fixer l'azote de l'air. Leucaena leucocephala est d'introduction récente mais n'a pas encore été adopté par les cultivateurs locaux. On a effectué jusqu'ici quelques essais de plantations dans le cadre de projets de développement et les espèces choisies semblent bien s'adapter aux conditions régionales.

Los bosques de Nepal han sido seriamente destruidos por sobreuso para efectos de forraje, y aun así yo calculo que el país tiene un déficit de forraje de unos 20%. La única fuente de forraje verde durante los secos inviernos en la mayoría del país, son los árboles forrajeros, de los cuales cerca de una docena son especies fijadoras de nitrógeno. La Leucaena leucocephala fue introducida recientemente pero aún no ha sido aceptada por los agricultores locales. En proyectos de desarrollo ha habido algunas pruebas de crecimiento y las especies parecen bien adaptadas a las condiciones locales.

The forests in Nepal have been seriously depleted over the last few decades, with the main destruction being caused by collection of fodder and animal grazing. At present, the domesticated animal population is about 15 million, with increases of about 2% annually. On the whole, I estimate that the shortage of fodder in the country is more than 20%.

Role of Fodder Trees

More than 35% of the estimated total feed is supplied by fodder trees, and the impact of the indiscriminate exploitation of the trees is felt in every aspect of the environment. The shoots, leaves, young twigs, and sometimes pods from trees around the farmlands and from forests have been traditional green forage for the dry winter (6 – 8 months) in most of the hilly and mountainous regions. In most areas, the trees supply the only green matter available to complement the dry, fibrous straws of rice, maize, and millets, which have low nutritive values. More than 75% of the tree fodder is used from November to April–June. The great potential for forage from trees cannot be overlooked. With better coordination of agriculture, forestry, and education, especially in research, a program using fast-growing trees could alleviate the feed shortage as well as the ecological degradation caused by forest depletion.

Nepal is rich in the variety of fodder trees. The great diversity of the bioclimatic conditions prevailing favours the establishment of no fewer than 110 different species of fodder trees. The growing of fodder trees or the use of tree forage is not practiced to any significant extent in the Tarai plains, but, in the mountains, even the cool temperate species, like *Quercus semecarpifolia*, are cut for forage and are browsed. About a dozen species from the Leguminosae family occur in Nepal including three *Bauhinia* sp. that are believed to be incapable of producing root nodules. Generally, however, Nepal can be regarded as poor in nitrogen-fixing tree species. The best fodder trees in the country are not leguminous. In fact, I am not aware of any scientific work being carried out in Nepal on leguminous fodder trees. Some trials on *Leucaena leucocephala* are being carried out by the Institute of Forestry in south Nepal but not from a fodder viewpoint. To establish plantations from local seed, one must identify individual trees for seed collection, reserve them, and pay the farmers for the seeds, in advance if necessary.

Leucaena leucocephala has been introduced to Nepal under various development projects, some of which have been fairly successful in terms of species' growth trials. The rejection of this species by farmers in the country has been the major constraint to its propagation on a large scale.

In the IHDP (Integrated Hill Development Project), East of Kathmandu Valley (ca 800–900 m), I know only two farmers who have tried it and, about 10 000 saplings, which were to be distributed free of charge, had to be destroyed after 3 years of waiting for someone to claim them. The Institute of Forestry in Hetauda has been conducting field trials on leucaena for about 2 years, as has the Community Afforestation Section of the Forest Department. The World Neighbour local office has been propagating the species at low altitudes, and interest in the species may be increasing.

As far as leucaena's fodder value is concerned, there are no trials on this subject at present in Nepal, and the farmers have not yet seen any positive contribution from *L. leucocephala* to their lifestyles, even though there has been some development-agency effort to encourage leucaena adoption. It is a challenge to scientists to come up with better species, and, to date, *L. leucocephala* has not met all the requirements of a fodder tree for Nepalese farmers.

Discussion Summary

Worldwide, the primary use of leucaena is for forage and feed. In Australia and in the Philippines, on a limited but growing scale, the crop is planted and grazed as pasture, whereas, in India and elsewhere, leucaena trees are grown in backyards, live fences, etc. and the leaves harvested by the farmers.

Direct seeding is common, although transplanting seedlings, which is more expensive, gives faster early growth. Careful weeding and soil amendment (Ca, P) are usually required, with weeding most often being done by hand in the developing world. Herbicides (glyphosate to kill existing weeds and Alachlor, preemergent) are effective but costly. Interplanting leucaena with *Imperata* and other perennial grasses is occasionally done but has drawbacks. Watering or irrigation is important in areas of extreme seasonal drought, and, in India, "protective irrigation" — watering just enough to ensure survival of plants during drought — is practiced.

The major obstacle to the use of leucaena as feed is the toxic effects caused by mimosine in the leaves and stems of the plant. However, current research on the subject has clarified the problem and provides the basis for processing the crop for increased use as animal feed. When eaten by ruminants, mimosine breaks down to DHP, which is a goitrogen, but, unlike mimosine, is not directly toxic and can be incorporated in feed at higher levels. In the past, researchers have assumed that microorganisms in the gut of the animals cause the breakdown,but recent evidence indicates that autolytic enzymes, present in fresh leucaena foliage, when brought in contact with the mimosine, are responsible for the conversion to DHP. Chewing fresh leaves causes the breakdown of about 30% of the mimosine before the meal reaches the gut in goats. Thus, chopping is viewed as an effective way of reducing mimosine content of leaf meal; however, drying inactivates the enzyme, as does contact with acid or high temperatures. Thus, the steps in processing the leucaena as feed are particularly important and deserve further study. Aluminum sulfate or iron sulfate application has been shown to reduce mimosine content in feed but is not a practical solution.

In ruminants, DHP has been shown to be metabolized in the rumen by a gram-negative anaerobic microbe. The microbe has not yet been identified because of the difficulties inherent in working with anaerobic conditions. Urine from goats fed leucaena leaf meal in Mauritius, Philippines, Seychelles, Indonesia, Hawaii, and Mexico was found to be DHP free, indicating the presence of beneficial rumen flora in these areas. Goats tested from Australia, Papua New Guinea, Fiji, and much of Africa had high levels of the deleterious DHP in their urine. Goats from nations like Brazil showed variable responses, the beneficial microbe being available in some of the population. It is believed that the microbe passes easily from one animal to another through the saliva or by other, undetermined anaerobic methods.

Researchers interested in testing their animals for the presence of DHP may inquire from Raymond Jones of the Commonwealth Scientific and Industrial Research Organization (CSIRO), Davies Laboratory, Townsville, Australia. Dr Jones has agreed to receive a limited number of urine samples from ruminants in areas previously untested, provided his directions are carefully followed.

Information on leucaena as a feed for monogastrics is limited. Studies on fish feeding have been done in the Philippines and India. The Indian trials utilized leucaena pellets suspended at different levels in fish ponds. Submerged feeders worked well also. Growth was good, but the economics are still unclear. Efforts at getting India's farmers to plant leucaena around ponds were initially unsuccessful, as farmers believed trees would poison the fish, would use too much water, and would lower the temperature of the pond. Despite these fears, the technique has been shown to have a great deal of promise. Extension efforts must include demonstration and information dissemination.

Leucaena as a feed for fowl has also come under scrutiny. High tannin content is believed to cause protein in the leaf to be bound and pass through the intestines without being as-

similated. Recent tests in Hawaii showed that mimosine slowed the growth rate and caused poor feather formation in Japanese quail. Most of the mimosine (75%) in pure leucaena diets showed up in the feces of the birds.

Perhaps the most unusual use of leucaena as a food by a monogastric animal is by humans. Leucaena is eaten in both processed and unprocessed forms. Among the processed foods are *tempe* and sprouts (Indonesia) and bean cake (Central America). Unprocessed young seeds, pods, and shoot tips are eaten in Thailand and Central America. Flowers are eaten in some areas, and a coffee-like beverage is prepared from roasted seeds. Indeed, a common name for leucaena in Australia is the "coffee bush." The processed foods in Indonesia appear to have reduced mimosine, and there is evidence that consumers differentiate between "sweet" and "bitter" local leucaena — a finding that implies various tannin contents. The differences between sweet and bitter varieties should be studied and may prove useful in efforts to breed varieties with low tannin contents.

Finally, it has been reported from several areas that leucaena has potential as a deworming medicine for both humans and animals.

Wood
Production

Closely planted leucaena can be cut every 4 - 5 years for wood production.

The Miracle Tree: Reality or Myth?

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Research in forestry is 40 years behind that of agriculture, although tissue culture techniques are a promising tool to speed up forestry research. No matter how fruitful are the findings of research, however, without adequate agronomic inputs, only marginal production will be obtained from trees planted on agriculturally marginal lands. Most of the tree planting (to include leucaena) in the developing countries will take place on agriculturally marginal lands. Demands for increased agricultural production to feed growing populations dictate that arable lands be used for sustained cropping. What people tend to forget is that marginal lands that will not sustain continued cultivation with agricultural crops will not sustain continued cropping with trees either. Trees require fertilizer, water, soil amendment, site preparation, etc. to reach maximum production and sustained yield. This is true of all trees, including leucaena despite its reputation as a miracle tree.

La recherche forestière est en retard de 40 ans sur la recherche agronomique, bien que la technique des cultures de tissus semble être un instrument prometteur pour atteindre des résultats plus rapides. Cependant, si fructueuses que se révèlent les observations des spécialistes, sans une contribution adéquate de l'agronomie, on ne pourra attendre qu'une production marginale des plantations d'arbres en terrains impropres à l'agriculture. Dans les pays en développement, la plupart des plantations (incluant Leucaena), s'effectueront dans des sols de ce genre. Dans ces pays, en effet, l'urgence d'accroître la production agricole pour nourrir des populations de plus en plus nombreuses oblige à consacrer les terres arables à une production agricole soutenue. Ce que l'on a tendance à oublier c'est que les terres marginales, que l'on ne peut cultiver régulièrement pour en retirer des récoltes soutenues, sont elles-mêmes impropres à entretenir des cultures arbustives permanentes. Les arbres cultivés ont également besoin d'engrais, d'eau, d'amendements du sol, de préparation du terrain pour atteindre un rendement satisfaisant et soutenu. Cette réalité est vraie pour tous les arbres, y compris Leucaena, malgré la réputation qu'on lui a faite d'arbre miracle.

La investigación forestal está 40 años atras de la agricultura, aunque las técnicas de cultivo de tejidos son un instrumento promisorio para acelerarla. Sin embargo, no importa cuán fructíferos sean los hallazgos de la investigación, sin insumos agronómicos adecuados, la producción de los árboles plantados en tierras agrícolas marginales, será marginal. La mayor parte de la plantación de arboles (para incluir leucaena) en los países en desarrollo tendrá lugar en tierras agrícolas marginales. Las demandas de una producción agrícola aumentada para alimentar las crecientes poblaciones exigen que las tierras cultivables sean usadas para el cultivo sostenido. Lo que la gente tiende a olvidar es que las tierras marginales que no pueden sostener la siembra continua con cultivos agrícolas tampoco podrán sostener la siembra continua de arboles. Los arboles requieren abonos, agua, preparación de suelo, lote, etc. para alcanzar la máxima producción y rendimiento sostenido. Esto es válido para todos los arboles, incluyendo la leucaena a pesar de su reputación como arbol milagroso.

Before asking whether leucaena is a miracle tree, perhaps one should first ask whether other "miracle" crops, such as rice, really were miraculous. On close examination, for instance, IR8 wasn't a miracle rice but a high yielding variety having certain desirable genetic characteristics, developed at a time when a major aim in development was to increase food production in the Third World. If there were a miracle, it was the scientific input into germplasm collection, testing, evaluation, selection, breeding, and development of management practices. However, to obtain the high yields, farmers must apply large amounts of fertilizers, pesticides, labour, etc.

Like the IR8 rice, giant leucaena (Salvador type, common varieties being K8, K28, and K67) was timely, appearing just when the devastating effects of deforestation first came to public attention. As Noel Vietmeyer of the National Academy of Sciences said, "Truly leucaena was a tree whose time had come". This fast-growing, multipurpose, leguminous tree came along when a miracle was needed. Deforestation was taking place so rapidly that

[1] These views are mine and not necessarily those of AID.

little hope was seen in countering it with traditional forest trees, which take many years to mature and are often incompatible with agriculture. Leucaena — and later other fast-growing, nitrogen-fixing trees — offered a light at the end of the tunnel. Hundreds of millions of dollars are now being spent on reforestation and related activities by development and donor agencies, multilateral lending institutions, private voluntary agencies, and governments in developing countries. Much of the reforestation is being done with fast-growing trees such as leucaena, but much of the money is wasted because of the lack of technical information, which, when available, has not been widely disseminated.

In many of these projects, leucaena has grown well, adding to its reputation as a miracle tree. However, its credibility has been seriously damaged by poor performance in many areas. For some: "the wonder ceases" (Halos 1980). Perhaps, through enthusiasm, leucaena's advocates have overstated the case, and expectations far exceed the genetic capabilities of the present germ-plasm base.

Researchers are working from a limited germ-plasm base from a collection made by James Brewbaker and his associates in Hawaii. Because of genetic uniformity, specific varieties of leucaena are susceptible to disease outbreaks such as affected potatoes and corn in the past. Leucaena is largely self-pollinating; however, there is some outcrossing if the crop is not maintained in isolation (R.J. Jones, personal communication). Perhaps the outcrossing is a blessing because, with the rapid proliferation of leucaena, it reduces the potential danger of epiphytotics. With the blessing, another problem has been inherited — varietal impurity — often resulting in unpredictable growth. If leucaena is to continue to be a solution to any development problems, its genetic improvement must be given high priority. The miracle rice had a distinct advantage because scientists had a wealth of domesticated varieties with which to work. However, the giant leucaenas are little more than "wildlings." The last intensive genetic improvement of the species was by the pre- and postcolonial Mexicans (Nahautl and Mixtec-Zapotec cultures) who selected leucaena for superior pod and seed size (Perez-Guerrero, in press).

Traditional foresters, when asked to explain growth differences of certain species of trees planted on the same site, all too often attempt to pass them off as a result of microsite differences. Rather, these growth differences could be a result of genetic variation caused by outcrossings of nondomesticated species.

Tissue culture, used in the generic sense of the term, is a biotechnique that is proving to be a valuable tool in tree improvement. The private sector is developing super trees (conifers), using tissue culture to clone trees that grow quickly, have superior form, and exhibit improved tolerances. These cloned trees are used for the establishment of seed orchards. Much of this work is closely guarded corporate secrets (Durzan 1979).

Recently, scientists (Venketeswaran and Romano 1982) at the University of Houston have reported the successful cloning, regeneration, and rooting of leucaena. This breakthrough has tremendous potential for the genetic improvement of leucaena and may help alleviate many of its limitations, such as insect problems, intolerance to saline soils, limited tolerance to acidic soils, etc. Tissue culture provides a relatively inexpensive method of screening thousands of samples of plant material within a small laboratory within a short time. It does away with the costly method of screening by outplanting, which may take years to provide improved varieties. Tissue culture also provides a more controlled atmosphere in which to screen plants. For example, cultured material from various genetic sources could be challenged with different levels of salts in a test for the best tolerance. Also, mutations might spontaneously occur or be induced through tissue culture, creating valuable new phenotypes (Nabors 1976).

Tissue culture is an excellent method of cloning trees that express superior or desired characteristics for the relatively rapid establishment of seed orchards of self-pollinating super trees. I have received reports of single super trees evolving from a stand of trees in which the rest of the trees were not spectacular. Professor Azad Osman (personal communication), University of Mauritius, reported that from one lot of K156 leucaena seed sent to him by Brewbaker last year one superior tree emerged from several hundred he planted. All of the trees expressed good growth and were relatively uniform except for one tree, which was outstanding. It was taller than the others; it grew more vigorously; and it developed more and larger leaves than did the others. Aart Van Wingerden (personal communication), Operation Double Harvest — Haiti, reported similar experience with K8. He planted more than 500

seedlings on a difficult site that had low fertility. All of the trees grew well, but one developed "head and shoulders" above the others. Are these specific hybrids, chance crosses, mutants, or tetraploids? No one knows. But these superior trees could be cloned through tissue culture and multiplied to create seed orchards of outstanding trees. The potential is there.

Tissue culture can also be used to develop disease- and insect-resistant varieties as well as plants that are more tolerant to pesticides. Peter Felker (personal communication), Texas A&I University, reported extensive insect damage to leucaena in south Texas, Brazil, and Argentina. Twig girdlers (*Oncideres pustalata* in Texas and *O. saga* in South America) have virtually wiped out some plantings of leucaena, and in one instance a single insect cut down a 3-m tree (Texas size).

A. Kretschmer and R. Builok (personal communication), Agriculture Research Station, Fort Pierce, Florida, reported that the caterpillars (*Ithome lassula*), larvae of a micro Lepidoptera (moth), are destroying the cannonballs (florets) of leucaena in Florida before they have a chance to mature. As a result, the trees do not set seed. They believe that the insects may also retard growth and reduce yield. Whether all varieties are susceptible to attack is uncertain. Common and Beattie (1982) reported similar findings in northern Queensland, Australia, and, in Bogor, Indonesia. Similar findings have been reported in Puma, India. Bullok has also observed a problem of psillids (sapsuckers) attacking young developing foliage, the effect of which is dieback and retarded growth. I (1979) made a similar observation at Semerang, central Java, Indonesia.

On the brighter side, Pat Dugan (personal communication), AID, Philippines[2], reported that Bobok Sawmill Company, Benguet Province, has, over the last few years, been able to increase the altitude tolerance of giant leucaena by several hundred metres by incrementally planting the crop up the side of a mountain; this report, however, needs verification.

Research in forestry is 40 years behind that of agriculture (Durzan 1979). Without adequate agronomic inputs, only marginal production will be obtained from trees planted on agriculturally marginal lands, and, unfortunately, most of the tree planting in the developing countries in the future will take place on agriculturally marginal lands. Demands for increased agricultural production to feed growing populations dictate that lands suited for sustained agricultural production be used for such. If these agriculturally marginal lands will not sustain agricultural production, neither will they sustain the continued cropping of trees.

In this respect, trees are no different from any other crop (such as corn) requiring fertilizer, water, soil amendment, site preparation, etc. to produce maximum and sustained yields. If trees are cropped on a short-term rotation, such as proposed for dendrothermal projects (generation of electricity with wood-fueled steam plants), nutrients mined from the soil will have to be replaced if high yields are to be sustained. Even though leucaena and other leguminous trees fix nitrogen, they need phosphorus for maximum growth. There are other nutrients whose absence will limit leucaena and other tree growth (Benge and Curran 1976). It is reported that adequate levels of molybdenum are necessary for maximum efficiency of nitrogen production by *Rhizobium*, and some research indicates that nitrogen utilization may be linked to phosphorus availability (Allen and Duzan 1982). However, Mike Dow (personal communication) of the National Academy of Sciences recently told me that scientists in the Congo reported to him that, when they applied phosphate to leucaena plantings, growth was depressed. They theorized that the phosphate is complexing with some other trace element, such as molybdenum, such that the uptake is limited. Inadequate amounts of boron also can reduce tree growth (Ladrach 1980).

Little is known about the association of mycorrhizal fungi with leucaena (and with most other trees). Mycorrhizal fungi facilitate the uptake of phosphorus and other nutrients and can transform unavailable forms of fixed phosphorus into forms available for plant uptake. They also increase the efficiency of fertilizer utilization, reducing application costs (Johnson and Menge 1982). Research has shown that, in the absence of mycorrhiza, growth of leucaena (Bob Davis, personal communication) and other trees is reduced, and many trees will not grow unless inoculated.

Most of the agriculturally marginal lands in Asia, especially those dominated by *Imperata cylindrica*, are deficient in phosphorus, and what little is present is in a form unavailable to leucaena. Mycorrhiza can transform this un-

[2] Now consulting for the World Bank.

available form of phosphorus into available forms; however, the strains of mycorrhiza associated with trees may be absent from these lands (John Gordon, personal communication).

Without adequate amounts of phosphorus, trees will grow poorly on these lands, and continuous cropping with sustained yield will be impossible. This fact became evident with the poor yields of leucaena grown on *Imperata* lands by Mabuhay Agro-forestry Corporation and a Japanese firm in Illegan, Mindanao, Philippines. Concern over this phenomenon has been expressed in response to the optimistic forecasts of leucaena yields from similar lands set aside in the Philippines for dendrothermal projects.

Peter Felker (personal communication) is planning pioneer research on mycorrhizal association with leucaena and its effect on phosphorus utilization. He will start his research, working with six cultivars of mycorrhiza from a collection from Purdue University, in cooperation with J.A. Menge of the University of California at Riverside. According to Felker, Menge has recently successfully isolated mycorrhiza from mesquite.

In conclusion, unless leucaena (and every other fast-growing, nitrogen-fixing tree) is treated as an agricultural crop, with emphasis being placed on genetic improvement, breeding, nutrient needs, pest control, proper management techniques, etc., it will cease to be regarded as a miracle tree and become a marginal tree on marginal land — a tree whose time has passed.

Wood-Yield Prediction Models for Leucaena Plantations in the Philippines

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Three acceptable yield-prediction models for leucaena plantations in the Philippines were developed in this study. The models provide annual yield estimates that are only 18–25% (15–25 m³/ha) of earlier estimates by others. This discrepancy is probably a reflection of the source and amount of data used: early estimates were mostly based on measurements of trees either in small patches or in single or a few rows. In contrast, my data come from 156 plots in actual forest plantations.

Cette étude a établi trois modèles acceptables pour les prévisions de rendement des plantations de Leucaena, *aux Philippines. Ces modèles fournissent des prévisions de rendement annuel qui n'égalent que 18 à 25 % (15 à 25 m³/ha) des estimations antérieures effectuées par d'autres personnes. Cette différence reflète probablement les sources d'origine et la quantité des informations utilisées. Les évaluations précédentes étaient fondées principalement sur des mesures prises dans de petits lots boisés, sur des sujets isolés, ou sur quelques rangées. Par contre, mes informations proviennent de 156 lots de véritables peuplements forestiers.*

En este estudio se desarrollaron tres modelos aceptables de predicción de rendimiento para las plantaciones de leucaena en Filipinas. Los modelos ofrecen cálculos de rendimiento anual que son solamente 18–25% (15–25 m³/ha) de cálculos hechos anteriormente por otros. Esta discrepancia es probablemente un reflejo de las fuentes y la cantidad de datos usados: los cálculos anteriores estaban prácticamente basados en mediciones de árboles en pequeños lotes o en una o pocas hileras. En contraste, mis datos provienen de 156 lotes en plantaciones forestales reales.

The giant varieties of leucaena, particularly those identified for wood production, have been widely used in tree-planting projects in the Philippines in the last decade. This great interest in the fast-growing varieties of leucaena was triggered by increasing demands for fuelwood and small poles, growing scarcity of timber in certain areas, ease of plantation establishment (on suitable sites), high specific gravity of the wood, suitability of the wood for various industrial products (charcoal, particleboard, dissolving pulp, etc.), and particularly high-growth estimates.

The early estimates of annual growth of giant leucaena varied from 40 t/ha to 80 t/ha, which are fantastic growth rates under real-forest conditions. These early estimates remind me of those for *Albizia falcataria*, whose yearly growth was projected as 100 m³/ha. As it turned out, *A. falcataria* grows only about 25 m³ on the average site in actual forest plantations.

In late 1977, my colleagues and I measured 56 temporary growth plots of leucaena in various plantations in the country representing different ages (mostly 1–3 years and a few 5 and 10 years), plant spacing, and site conditions. Using these data, we developed yield-prediction models and found that the annual growth rate of leucaena plantations was about 30 m³/ha on the average site.

Since then, we have gathered yield data on 100 additional plots, and this report presents the results of analysis for all 156 plots.

Data Collection and Collation

Temporary yield plots were located and measured in existing plantations in various parts of the Philippines. Plots were selected for the widest representation of stand ages, plant spacing, and site classes. Each plot was sampled by the Bitterlich method, with a basal-area factor of 2 m²/ha. The sample trees were measured for DBH (diameter, breast height) and for merchantable height (up to 5 cm in diameter). The total heights of dominant and codominant trees were also measured, and the age of each plot was recorded. The age, mean stand total height, mean stand DBH, stand basal area, and stand volume were recorded for each plot and were used in developing the yield-prediction models.

Table 1. Site index (base age = 5 years).

	Site index (m)				
Age	8	10	12	14	16
1	3.1	3.9	4.7	5.5	6.3
2	5.6	7.0	8.4	9.8	11.3
3	6.8	8.6	10.3	12.0	13.7
4	7.5	9.4	11.3	13.2	15.1
5	8.0	10.0	12.0	14.0	16.0
6	8.3	10.4	12.5	14.6	16.6
7	8.6	10.7	12.8	15.0	17.1
8	8.7	10.9	13.1	15.3	17.5
9	8.9	11.1	13.3	15.5	17.8
10	9.0	11.2	13.5	15.7	18.0

Table 2. Yield (m^3/ha): single-equation model (no spacing).

	Site index (m)				
Age	8	10	12	14	16
2	1.8	3.9	8.4	18.0	38.8
4	17.0	30.0	52.7	92.7	163.0
6	36.0	59.2	97.3	160.0	263.1
8	52.3	83.1	132.2	210.2	334.2
10	65.4	101.9	158.9	247.6	385.8

Model Development

The basic stand yield-prediction model used in this study was:

Site-index function

$\log S = f_1 (A, H)$;

Stand DBH function

$\log D = f_2 (H, A)$;

Stand basal-area function

$\log B = f_3 (A, SP)$; and

Stand-volume functions

$\log V = f_4 (A, S, SP)$ for single-equation models, and

$\log V = f_5 (B, H)$ for the system-of-equations model

where S = site index (m) at age 5 years; A = stand age in years; H = total height (m) of stand; D = stand diameter, breast height (cm); B = stand basal area (m^2/ha); SP = initial planting spacing (m^2); and V = stand volume or yield (m^3/ha).

We used two regression methods to specify the leucaena yield-prediction models: ordinary least squares and two-stage least squares. The latter required the formulation of a system of just-identified equations. More than 20 variants of the models were worked out before we found some acceptable ones, which we validated for goodness of fit and significance of the regression coefficients, conformity with the basic shape and differentiation properties of the yield function, and ability to predict real-world values.

Results

The specific form of the site-index guide equation is:

$$\log H = b_0 + b_1/A^{**}k;$$

where $b_0 = 1.186$; $b_1 = 0.5094$; $k = 1.00$; $R^2 = 0.84$; and ** is the exponentiation operator.

Thus, at a base age of 5 years, the site index (Table 1) is:

$$\log S_i = -0.1019 + 0.5094/A_i + \log H_i.$$

Two single-equation yield-prediction models were found acceptable (Tables 2 and 3) where $R^2 = 0.87$:

$$\log Y = 1.575 - 5.295/A + 0.1750\,S/A + 0.07883\,S; \text{ and}$$

$$\log Y = 1.078 - 4.990/A + 0.1501\,S/A + 0.1196\,S - 0.007226\,S^*SP + 0.08547\,SP.$$

One system-of-equations model was found acceptable in this study (Table 4):

$$\log H = 0.1019 - 0.5094/A + \log S; \text{ where } R^2 = 1.00;$$

$$\log B = 2.019 - 2.452/A - 0.3320\,SP; \text{ where } R^2 = 0.71;$$

$$\log V = -3.344 + 0.3294 \log B + 4.398 \log H; \text{ where } R^2 = 0.85.$$

All three models conform to the validation

Table 3. Yield (m^3/ha): single-equation model (with variable spacing).

Age	Site index (m) 8	10	12	14	16
		1 m × 2 m spacing			
2	1.6	3.6	8.3	18.9	43.4
4	13.9	26.8	51.7	99.8	192.6
6	28.8	52.4	95.4	173.7	316.4
8	41.4	73.2	129.6	229.2	405.6
10	51.5	89.5	155.7	270.7	470.7
		2 m × 2 m spacing			
2	1.8	3.8	8.2	17.6	37.8
4	15.8	28.5	51.5	92.9	167.6
6	32.7	55.7	94.9	161.6	275.4
8	47.0	77.8	123.8	213.2	353.0
10	58.5	95.1	154.8	251.8	409.7
		2 m × 3 m spacing			
2	2.0	4.1	8.2	16.4	32.9
4	17.9	30.3	51.2	86.4	145.9
6	37.1	59.2	94.3	150.4	239.7
8	53.4	82.7	128.1	198.4	307.3
10	66.4	101.1	153.9	234.3	356.6
		3 m × 3 m spacing			
2	2.5	4.5	8.1	14.7	26.7
4	21.7	33.2	50.7	77.5	118.5
6	44.9	64.8	93.5	134.9	194.6
8	64.6	90.6	127.0	178.0	249.5
10	80.4	110.7	152.6	210.2	289.6

Table 4. Yield (m^3/ha): system-of-equations model.

Age	Site index (m) 8	10	12	14	16
		1 m × 2 m spacing			
2	1.6	4.2	9.3	18.4	33.0
4	9.1	24.2	53.9	106.1	190.9
6	16.3	43.4	96.7	190.5	342.7
8	21.8	58.1	129.5	255.2	459.1
10	25.9	69.2	154.4	304.1	547.2
		2 m × 2 m spacing			
2	1.5	4.0	8.9	17.5	31.4
4	8.6	23.0	51.2	100.9	181.6
6	15.5	41.2	91.9	181.1	325.9
8	20.7	55.2	123.2	242.7	436.6
10	24.7	65.8	146.8	289.2	520.3
		2 m × 3 m spacing			
2	1.4	3.8	8.4	16.6	29.9
4	8.2	21.8	48.7	96.0	172.6
6	14.7	39.2	87.4	172.2	309.9
8	19.7	52.5	117.1	230.7	415.1
10	23.5	62.6	139.6	275.0	494.8
		3 m × 3 m spacing			
2	1.3	3.5	7.8	15.4	27.7
4	7.6	20.3	45.2	89.0	160.1
6	13.6	36.4	81.1	159.7	287.3
8	18.3	48.7	108.6	213.9	384.9
10	21.8	58.0	129.4	255.0	458.8

Table 5. Results of the independent test, based on 28 validation plots.

	Model 1	Model 2	Model 3
Sum of deviations	-105.9	-92.4	-14.6
Mean of deviations	-3.8	-3.3	0.52
Range	-39.8 - 16.6	-49.4 - 15.0	-30.1 - 14.5
Standard error	2.89	2.92	2.22
Computed t-value	1.31	1.13	0.23

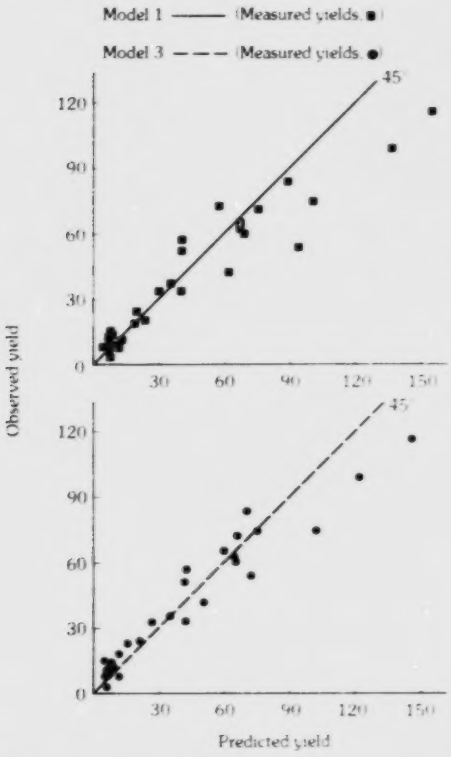

Fig. 1. Independent test: observed vs predicted yields (model 1 overestimates yield)

criteria. In the independent test, the mean of the differences between the observed and predicted yields was not significantly different from zero in all cases (Table 5).

The three models give equally acceptable predictions of yields for leucaena (giant varieties) plantations in the Philippines (Fig. 1). Although the first model does not include planting spacing as an explanatory variable, the second and third models do. Both the first two models consider site index as an a-priori variable. In other words, if the site-index equation were taken as part of a system of equations with the yield equation, there would be an identification problem; as such, the regression coefficients would be biased and inconsistent. The third model eliminates such a problem.

Conclusions

The plantations from which we gathered our yield data are not intensively managed, and, thus, there is a need to continue this study so that the effects of appropriate cultural activities like liming, fertilizer application, *Rhizobium* inoculation, and thinning can be taken into consideration. Related to this is the need to express site quality as a function not only of stand total height and age but also of soil, climatic, and other site factors. There is also a need for researchers to look into the long-term effects on yield of a succession of leucaena crops.

Effect of Spacing on Growth of Leucaena

Rick J. Van Den Beldt *Nitrogen Fixing Tree Association, Waimanalo, Hawaii, USA*

In Hawaii, the augmented block design is used to study the effects of population and environment on growth and yield of leucaena. Identical experiments involving 12 spacings were planted at four locations in Hawaii and environmental parameters examined for influence on growth. Volume growth was poorest at the Maui site where soil calcium levels were quite low. Generally, increasing population reduced both height and diameter development of individual trees, but stand volume was largest in the range of 10 000 –20 000 stems/ha.

À Hawaii, on a recours à la méthode des blocs progressifs pour étudier les effets de la densité de peuplement et de l'environnement sur la croissance et le rendement de Leucaena. Dans des expériences identiques portant sur 12 espacements, on a étudié des plantations dans quatre endroits d'Hawaii et examiné l'influence de paramètres de l'environnement sur leur développement. L'accroissement volumétrique s'est révélé le plus faible au site principal où le sol manquait nettement de calcium. De façon générale, l'accroissement de la densité des peuplements a eu pour résultat de réduire le développement des arbres tant en hauteur qu'en diamètre, et le volume du peuplement a été le plus élevé avec une densité de 10 000 à 20 000 plants à l'hectare.

En Hawaii el diseño del bloque aumentado se usa para estudiar los efectos de la población y el ambiente sobre el crecimiento y el rendimiento de la leucaena. Se sembraron experimentos idénticos con 12 espaciamientos en cuatro localidades de Hawaii y se examinaron los parámetros ambientales para determinar su influencia sobre el crecimiento. El más bajo crecimiento en volúmen se presentó en el sitio principal donde los niveles de calcio del suelo eran bastante bajos. Generalmente, el aumento de la población redujo tanto el desarrollo de la altura como del diámetro en los árboles individuales, pero el mayor volumen se presentó en la gama de 10 000 –20 000 troncos/ha.

In 1978, work was started at the University of Hawaii to examine the effect of spacing on wood yield and quality of leucaena. Although my colleagues and I hoped that results of the experiments could be used by the wood industry in general, our primary purpose was to examine leucaena as a fuelwood.

The role of leucaena as a fuelwood in Hawaii has been explained elsewhere by Brewbaker (1980a), who recommends establishing a 400-ha plantation at about 10 000 stems/ha, to be harvested on a 4-year rotation by a swathe-felling mobile chipper. Chips from the plantation would be burned to produce about 12×10^6 kWh annually, or about one-third of Molokai's energy needs. This scheme was viewed to be profitable, with a rate of return of about 6 – 10%, unadjusted for inflation.

My efforts address the use of leucaena in production of fuelwood by individual households in the tropics. A model of ultra-dense tree populations and short rotations involving small land areas is being developed that enables a rural household to become self-sufficient in fuelwood while producing a small amount of wood for sale. At average growth rates in Hawaii, an estimated 0.1 – 0.2 ha would be required, with 20 000 – 30 000 trees/ha, harvested every 1 – 2 years.

Augmented Block Design

The leucaena-spacing experiments on which the model is being based are in the augmented block design of Federer and Raghavarao (1975). The design allows one to ask questions of both a fairly advanced nature, with replications, and a preliminary nature for which replication is unnecessary. For example, one planting utilizing the augmented block design consists of four replications of six plots each (Fig. 1). Each replication has four replicated treatments and two unreplicated, or augmented, treatments. The replicated treatments are 5000, 10 000, 20 000, and 40 000 plants/ha. Augmented treatments range from 2500 plants/ha (preferred by foresters) to 80 000/ha, about the population density of a cornfield.

Analysis of variance is performed only on the replicated treatments, and experimental variations thus derived are used in tests of the augmented treatments. Augmented treatments are adjusted, according to the replication in which they are located, by the formula:

$$T_{adj} = T_{unadj} - X_{i.} + X_{..};$$

where T_{adj} = adjusted treatment mean; T_{unadj}

Spacing (m)	Plot number	Spacing	Plot number
1 × 0.25*	101	1 × 0.25*	406
1 × 2*	102	1 × 2.5	405
1 × 1.5	103	1 × 2*	404
1 × 1*	104	1 × 0.75	403
1 × 0.5*	105	1 × 0.5*	402
1 × 3	106	1 × 1*	401
1 × 1*	201	1 × 1*	306
1 × 2*	202	1 × 0.375	305
1 × 0.25*	203	1 × 0.25*	304
0.5 × 0.25	204	0.5 × 0.33	303
1 × 4	205	1 × 2*	302
1 × 0.5*	206	1 × 0.5*	301

48 m

12 m

Fig. 1. Augmented block design of University of Hawaii leucaena spacing studies: plots consist of four rows spaced 1 m apart, with variable spacing within rows. Data are taken from centre rows at regular intervals. Means of augmented (nonreplicated) treatments are adjusted according to the replication in which they occur (= replicated treatment).*

= unadjusted treatment mean; $X_{i.}$ = mean of replicated treatments incorporating augmented treatment; and $X_{..}$ = overall mean of replicated treatments.

The augmented block design has the distinct advantage of incorporating far more treatments than the randomized block design used widely in forestry and agriculture. In all, 12 spacings at each site are examined for parameters of growth — height and diameter — over 4 years.

Effect of Site on Volume Growth

The trials consist of identical experimental designs on the islands of Maui, Molokai, Kauai, and Oahu (Waimanalo). Rainfall varies from site to site (Table 1) but, because of irrigation, it is not a major factor in growth of the stands. The Molokai planting is drip irrigated to compensate for poor rainfall. Above a minimum of 1000–1200 mm/year for good growth of leucaena, the distribution of rainfall is more important than the amount. Average temperatures do not vary too much among the sites; all locations have either a isohyperthermic or hypothermic temperature regimen. Low average daily temperatures on Molokai are offset by high daytime temperatures. Kauai, despite the low average daytime temperature, had high volume growth.

The four sites represent two mollisols, an oxisol, and an aridisol (Table 1). Soil pH ranges from 5.1 to 6.5 and does not seem to affect leucaena growth too much. More important is the calcium content of the soils, lowest on Maui (0.4 meq/100 g), where stand growth was the lowest of all sites.

The formula of Kanazawa et al. (1982) was used in calculations of tree volumes. The formula is:

$$\text{Volume} = 0.5 \times \text{DBH}^2 \times \text{height};$$

where DBH is diameter (m), breast height; height is total plant height (m).

Plot volumes (Table 2) were based on average measurements from 10 trees selected randomly and expanded to a per-hectare basis.

A generalization usually made by those familiar with leucaena is that per-hectare volumetric growth in the short term is enhanced by increasing population. This trend was seen in the 1st year data from the Waimanalo and Maui sites, where mean annual increment (MAI) and increasing population had a near linear relationship. However, the Kauai and Molokai sites showed either maximum growth at 20 000 plants/ha or equal growth between the 20 000 and 40 000 plants/ha plots. Maui retained the pattern of linearly increasing volume growth through year 2. Curiously, Kauai developed the trend in the 2nd year but lost it the following year.

The variations in response to spacing at

Table 1. Climate and soil characteristics[a] of planting sites.

Location	Rainfall[b] (mm)	Temperature (°C)[c] High	Low	Soil type	pH	Ca (meq/100 g)	Mg (meq/100 g)	K (meq/100 g)	CEC
Waimanalo	1605	27.3	20.7	Vertic haplustolls, very fine, kaolinitic, isohyperthermic	6.5	19.3	7.5	1.7	26.3
Kauai	2332	25.7	20.1	Typic gibbsihumox, clayey, ferritic, isothermic	5.1	1.2	0.2	0.1	11.0
Molokai	777	28.4	14.4	Ustollic camborthid, fine-loamy, kaolinitic, isohyperthermic	5.4	3.0	2.3	0.8	8.8
Maui	1069	30.0	18.0	Typic haplustolls, fine, kaolinitic, isohyperthermic	6.5	0.4	0.3	0.2	—

[a] Values for soil are the average in depth of 1 m.
[b] Average annual rainfall during the experiment.
[c] Average annual temperatures during the experiment.

different locations will almost certainly make yield-prediction models as a function of environment unreliable.

Leucaena is self-pollinated and highly uniform genetically; thus, between-tree variation is caused by interplant competition. In widely spaced plots, competition is minimized, as is variation of volume between stems. In closely spaced plots, competition is severe, and variability increases, with some stems assuming the form and growth of larger neighbours in wider-spaced plots. The great majority of stems in closely spaced plots remain stunted and are overtopped by the end of the 1st year. Indeed, stand-volume growth in high-population treatments is probably a reflection of the stems that grow large at the expense of suppressed individuals.

Table 2. Growth of *L. leucocephala* at four sites in Hawaii.[a]

Location spacing (m × m)	1 year DBH (cm)	1 year Height (m)	1 year MAI[b]	2 years DBH (cm)	2 years Height (m)	2 years MAI	3 years DBH (cm)	3 years Height (m)	3 years MAI	4 years DBH (cm)	4 years Height (m)	4 years MAI
Waimanalo												
1 × 2	4.5	5.9	29.8	5.9	8.0	34.2	6.5	9.6	34.1	7.6	11.0	39.1
1 × 1	4.2	6.5	57.1	5.7	8.5	68.6	6.3	10.3	67.2	6.9	11.4	68.4
1 × 0.5	3.5	5.6	67.1	4.5	7.8	77.5	5.0	8.8	71.6	5.5	9.6	71.7
1 × 0.25	2.7	5.3	77.1	3.1	6.9	64.2	3.1	7.6	48.0	3.6	8.2	51.8
Kauai												
1 × 2	5.1	6.0	38.2	6.8	9.3	53.6	7.7	10.4	51.0			
1 × 1	3.9	5.9	45.4	5.7	8.4	68.2	7.0	10.0	80.6			
1 × 0.5	3.8	6.4	92.8	4.9	7.8	93.6	5.6	8.7	90.6			
1 × 0.25	2.4	5.2	58.3	4.0	6.7	104.2	4.1	7.3	82.2			
Molokai												
1 × 2	5.4	6.8	48.4	6.7	9.2	52.1						
1 × 1	4.9	6.6	78.0	5.5	9.4	70.2						
1 × 0.5	3.8	6.4	92.8	4.2	8.3	74.7						
1 × 0.25	2.8	5.6	90.0	3.1	7.1	69.2						
Maui												
1 × 2	2.2	2.9	3.4	4.2	5.3	11.4						
1 × 1	2.2	3.0	7.6	3.7	5.2	17.9						
1 × 0.5	2.3	3.5	18.7	3.6	5.6	36.4						
1 × 0.25	1.8	3.2	19.7	2.8	5.2	39.9						

[a] Standard deviation for DBH and height at 5% level of significance was Waimanalo 0.46, 0.48; Kauai 1.14, 0.83; Molokai 0.50, 0.52; and Maui 0.58, 0.41.
[b] MAI = mean annual increment, volume/ha ÷ age. Volume calculated with Kanazawa's model.

Height and Diameter Development

At the Waimanalo planting, located on Oahu about 30 km from the University of Hawaii campus, height and diameter data were taken from 10 trees selected randomly from the two central rows of each plot every 3 months for the 1st year and every 6 months in succeeding years, although only annual data are presented here. The data (Fig. 2) were combined for all ages and spacings, and a comprehensive standard deviation was computed at the 5% level of significance. One should use this standard deviation to compare means of the replicated treatments and, with caution, to compare augmented treatments.

As could be expected, the trees at wider spacings had greater diameters than those of the same age at close spacings. As populations decreased from 10 000/ha, the average diameters increased as much as a centimetre or more between populations that differed by only a few thousand stems/ha. This is significant, as tree volume is a function of the square of diameter. Thus, the yearly per-tree increment of widely spaced stands is many times that of close spacings.

At close spacings (≥20 000/ha), diameter growth was suppressed at an early age. At very close spacings, diameter growth essentially stopped at the end of the 1st year. Nevertheless, the number of stems offset this lack of growth, generally making closely spaced plantations more productive on a per-hectare basis during the 1st several years of growth.

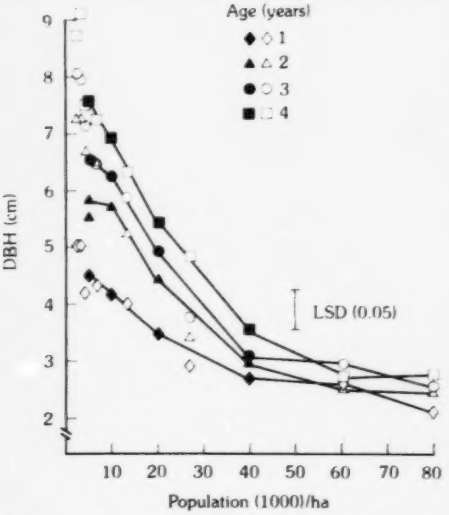

Fig. 2. Diameters (breast height) of leucaena at different spacings and ages (solid symbols = replicated treatments; open symbols = augmented treatments).

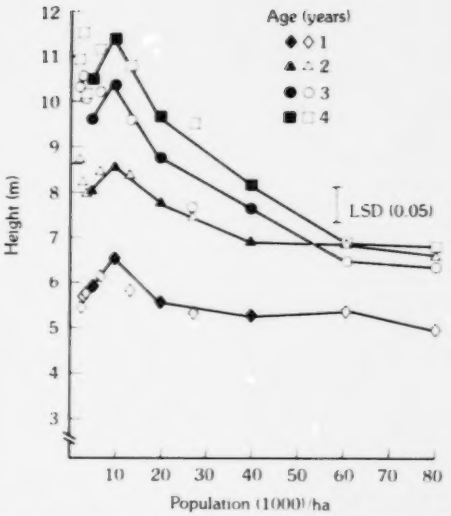

Fig. 3. Heights of leucaena at different spacings and ages at Waimanalo, Hawaii (solid symbols = replicated treatments; open symbols = augmented treatments).

Height growth is much less affected by spacing than is diameter development. Even at spacings of 60 000 and 80 000/ha, height growth did not stop until the 2nd year. Height development was essentially linear for each year across spacings within the range of 2500–20 000/ha. One should not pay too much attention to the height superiority of 10 000/ha over 5000/ha at all ages. This effect was not noted at other sites and is probably a function of the experimental randomization process. Overall, height increments get smaller at all spacings as age increases and probably taper off in wider spacings as trees reach a maximum 13–15 m. Height growth in these treatments will not affect stand-volume growth as much as annual diameter increments.

Spacing as a Management Tool

The trick to using spacing as a management tool is to keep in mind three major determinants:

- The age at which the particular spacing will inhibit growth. Different spacings give

Wood cut from 2-year-old leucaena thinnings from a stand of 20 000 plants/ha is suitable for household fuelwood.

optimum per-hectare volumes at particular ages. Thus, one would harvest a 40 000 stems/ha planting before the 1st year, when diameter growth stops rather than waiting 3–4 years, when growth is clearly suppressed. Alternatively, one would not harvest a 5000/ha planting at 2 years, preferring instead to allow the stand to take advantage of superior diameter growth (and thus higher volume growth) in later years.

- The use intended for the product. If household firewood is to be obtained, close spacings (20 000–40 000/ha) would be suitable, producing uniform stems about 3–4 cm in diameter and 5–6 m in height. Allowing the stand to grow beyond this age would give material of variable size, the largest of which would be difficult to harvest and split at the household level. Similarly, the optimum plant density for poles for which uniformity is required would be 10 000–20 000/ha over a 3–4 year rotation. For pulpwood production, wider spacings 5000–10000/ha or less on a 4–5 year rotation would be superior. Where labour is cheap, the stand could be established at closer spacings and thinned back to the desired stocking density by 2–3 years.
- The site quality. In poor sites, it is proba-

Leucaena wood is used for construction of animal pens at a farmers' education centre in Indonesia.

bly better not to opt for long rotations and low per-hectare populations. Growth would be so slow that weed competition would be a continual problem. The wise manager would opt for either more suitable species or closer spacings and modification of desired product size. The Maui site is a good example: because of nutrient-poor soils and weed competition, growth of the trees in wide spacings has been slow, and maximum yield has been obtained from the close spacings.

Biomanagement of Leucaena Plantations by Ion Exchange (India) Ltd[1]

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About 7000 m² have been under intensive tree farming since 1980 in the factory estate of Ion Exchange (India) Ltd at Ambarnath. There are 7700 plants of 20 diverse species, with Leucaena leucocephala *accounting for 6453.* Leucaena leucocephala *seedlings K8 and K28 (procured from Urulikanchan) were planted in April 1980. This is an account of experiments to study production of biomass/unit area in relation to variables like interplant density, irrigation (root and foliar), monoculture versus polyculture, pruning and harvesting, pest management, understories, and hormonal sprays. A study of leucaena as foliage meal for cattle and poultry is also summarized. Annual forage biomass (8–10% moisture) of 27.7 t/ha by extrapolation was obtained with an interplant density of 0.3 m × 0.3 m and nine harvests a year. Very close density plantings (2.5 cm × 2.5 cm) resulted in the generation of a microclimate conducive to infestation by* Pseudococcus *sp. A spacing of 1 m × 1 m yielded 20.62 t/ha biomass, whereas a spacing of 2 m × 2 m yielded 8.69 t/ha. Polyculture of selected species yielded total biomass of 8.26 t/ha; monoculture yielded 8 t/ha. Systematic pruning every quarter produced healthy growth in both systems. Foliar irrigation produced 24.3 t/ha in 6 months; root irrigation, 15.4 t/ha. Understories did well with foliar irrigation. Tissue layering was employed in* Casuarina equisetifolia, Gliricidia sepium, *and* L. leucocephala. *Cattle fed leucaena at 10% of their diet exhibited 20% higher milk yield than a control group; uptake was normal under stress caused by foot-and-mouth disease. Chickens fed leucaena foliage meal at 5% had 15–20% higher weight gain than controls over an 8-week period. Under stress resulting from coccidiesis and fowl-pox, the addition of 15% leucaena foliage meal to standard diet speeded recovery.*

Depuis 1980, Ion Exchange (India) Ltd, d'Ambarnath, affecte environ 7 000 m² des propriétés de l'usine à la sylviculture intensive. On y trouve 7 700 plants de 20 espèces différentes, dont 6 453 Leucaena leucocephala. *Des semis K8 et K28 de cette dernière (obtenus de Urulikanchan) ont été mis en terre en 1980. Nous donnons ici un compte rendu des expériences effectuées pour étudier la production de biomasse par unité de surface, compte tenu de variables comme la densité de plantation, l'irrigation (feuillage et racines), monoculture comparée à polyculture, taille et récolte, traitements antiparasitaires, sous-étages et pulvérisations hormonales. On résume aussi une étude sur la valeur de la farine de feuilles de* Leucaena *comme aliment des bestiaux et de la volaille. On a obtenu par extrapolation une biomasse annuelle de fourrage (8 à 10 % d'humidité) de 27,7 t/ha pour des écartements de 0,3 m × 0,3 m et neuf récoltes par an. Les plantations très serrées (2,5 cm × 2,5 cm) ont créé un microclimat propice à une infestation de* Pseudococcus. *L'écartement de 1 m × 1 m a donné un rendement de 20,62 t/ha de biomasse, et celui de 2 m × 2 m, de 8,69 t/ha. La polyculture avec des espèces choisies a produit 8,26 t/ha de biomasse totale, et la monoculture 8 t/ha. L'élagage systématique à tous les trimestres a été suivi d'une végétation vigoureuse dans le cas des deux systèmes. Avec irrigation du feuillage, le rendement s'est élevé à 24,3 t/ha en 6 mois, et avec irrigation des racines à 15,4 t/ha. Les sous-étages ont bien profité de l'irrigation foliaire. On a pratiqué le marcottage de tissus sur* Casuarina equisetifolia, Gliricidia sepium *et* L. leucocephala. *Les bestiaux dont la ration comprenait 10 % de* Leucaena *ont augmenté leur production laitière de 20 % par rapport à un groupe témoin. L'absorption a été normale malgré le stress d'une épidémie de fièvre aphteuse. Des poulets dont la ration contenait 5 % de farine de feuilles ont gagné en poids 15 à 20 % de plus que le groupe témoin, durant une période de 8 semaines. Pendant une période de stress due à la coccidiose et la variole aviaire, l'addition de 15 % de farine de feuilles de* Leucaena *à la ration normale a hâté la guérison.*

En los terrenos de la fábrica de Ion Exchange (India) Ltd en Ambarnath, unos 7000 m² han estado bajo cultivo intensivo de árboles desde 1980. De las 7700 plantas de 20 especies diversas, la Leucaena leucocephala *suma 6453. Las plántulas de* L. leucocephala *K8 y K28 (obtenidas de Urulikanchan) fueron plantadas en abril de 1980. Este es un relato de la experiencia para estudiar la producción de biomasa/unidad de área en relación con variables como densidad interplanta, irrigación (radical y*

[1] This paper was presented by G.S. Ranganathan, President, Ion Exchange (India) Ltd, at the workshop.

foliar), monocultivo versus policultivo, poda y cosechamiento, manejo de plagas, especies de menor tamaño, irrigaciones hormonales, etc. Se resume también un estudio de la leucaena como harina de follaje para ganado y aves. La biomasa anual del forraje (8–10% humedad) de 27,7 t/ha por extrapolación, se obtuvo con una densidad interplanta de 0,3 m × 0,3 m y nueve cosechas al año. Densidades de plantío muy cercanas (2,5 cm × 2,5 cm) resultaron en la generación de un microclima conducente a la infección por Pseudococcus *sp. Un espaciamiento de 1 m × 1 m arrojó 20,62 t/ha de biomasa, mientras que un espaciamiento de 2 m × 2 m arrojó 8,69 t/ha. El policultivo de especies seleccionadas arrojó una biomasa total de 8,26 t/ha; el monocultivo arrojó 8 t/ha. La poda sistemática cada 3 meses produjo un crecimiento sano en ambos sistemas. La irrigación foliar produjo 24,3 t/ha en 6 meses; la irrigación radical 15,4 t/ha. Las especies de menor tamaño dieron buen resultado con irrigación foliar. Con la* Casuarina equisetifolia, Gliricidia sepium *y* L. leucocephala, *se emplearon las capas de tejido. El ganado alimentado con leucaena al 10% en sus dietas presentó un rendimiento de leche 20% superior al grupo de control; la ingestión fue normal bajo la tensión causada por la aftosa. Los pollos alimentados con harina de follaje de leucaena al 5% tuvieron de 15–20% mayor ganancia de peso que el grupo de control en un período de 8 semanas. Bajo la tensión resultante de la coccidiosis y la viruela aviar, la adición del 15% de harina de hoja de leucaena a las dietas normales aceleró la recuperación.*

We at Ion Exchange (India) Ltd have been studying leucaena since 1980. Some of our findings are promising despite the environment of the experimental plots, which are located in a heavily polluted area containing acid fumes and phosphate dust. Better yields would be expected from an unpolluted environment.

Spacing Trials

At 0.3 m × 0.3 m spacing, 1277 seedlings were transplanted from December 1981 to January 1982 in a plot 126 m^2. The variety selected was K8 Ambarnath. Average height at transplantation was 60 cm. The first pruning-cum-harvesting (5 March 1982) produced 13 kg. Thereafter, every 40 days, the harvest was 120 kg of foliage until July 1982 — a total of 373 kg (by extrapolation, 29.4 t/ha). At the end of the 1st year, we expect to harvest 973 kg (76.8 t/ha) in nine harvests. The amounts should further increase by the end of the 2nd year when a harvest of 130 kg is expected or 1.2 t (92.3 t/ha) in nine harvests.

Foliar irrigation was by sprinkler (1.8 m long), with a meter fitted at the base. The sprinkler was used for 3 min at 15 locations, every 4 days, providing about 300 L water each time. Celmone (alpha-naphthalene acetic acid) hormone at 20 ppm was used twice as a foliar spray to stimulate foliage growth.

For studies of very close spacings (2.5 cm × 2.5 cm), as suggested by Romm (1979), seeds were planted in two adjacent beds, each 12 m × 1.2 m × 0.12 m, in July 1980; 23 000 seeds germinated in each bed. In one bed, 52 plants are now more than 3.2 m tall and continue to grow, whereas 111 plants are only 1.2 m. In the adjacent bed, 47 continue to grow and are now 3.5 m tall, and 175 plants are stunted (1.1 m). In both beds, the trees at the periphery have grown well. Although all the seeds germinated, only 385 plants rooted well and, of these, only 99 did very well. The rest were stunted. Mortality may have been caused by insufficient sunlight, overcrowding, or attack from pests.

A pest was observed in the last week of November 1981: host plants appeared to have fungus — a whitish mycelium all over the plant. Closer examination revealed tiny, white bugs inside the encrustations, moving slowly on the foliage. The white threads were excretions from the insects, identified as *Pseudococcus* sp., sedentary mealybugs belonging to the family Pseudococcidae.

A concentrated spray of Nuvan® (active ingredient, dichlorovas) was applied at 20 ppm. After 10 days, a spray of Rogor® (active ingredient, dimethoate) was applied at 40 ppm. After a week, both plots were pruned and defoliated. The mealybugs were almost completely eradicated.

Planting at 2.5 cm × 2.5 cm spacing created a microclimate conducive to infestation, but systematic pruning might have prevented the insect's occurrence. Plants in adjacent plots were not affected. For confirmation, double-blind trials of these experiments are in progress.

No other significant disease or pest was noticed, although one plant had gummosis in March 1982. This plant had very little foliage but, after heavy pruning, developed thick foliage. In the monsoon of 1981, 25 trees died because of waterlogging.

Trials on biomass yield from plants at spacings of 1 m × 1 m (350 trees) and 2 m × 2 m (90 trees), with root irrigation, have also been conducted. Two plots, 350 m^2 each, were planted in the field in June 1980 (Table 1). Total biomass, extrapolated to per-hectare and

Table 1. Biomass yields (wet basis) from leucaena plots at two spacings (1 m × 1 m, 2 m × 2 m).

	1 m × 1 m spacing		2 m × 2 m spacing	
	Biomass, 7/82 (kg/tree)	Pruning 12/81 + 5/82 (kg/plot)	Biomass, 7/82 (kg/tree)	Pruning 12/81 + 5/82 (kg/plot)
Foliage	0.65	493.5	0.72	125
Wood	1.45	335.0	3.50	97
Per-hectare basis				
Foliage	6500	14100	1861	3571
Wood	14500	9571	8998	1071

dry-weight basis (10–15% moisture) was 20.6 t at 1 m × 1 m spacing and 8.69 t at 2 m × 2 m.

Polyculture versus Monoculture

Two plots (395 m^2 each) were planted in June 1981 for a comparison of monoculture leucaena with a polyculture. Spacing was 1 m × 1 m, and plants were 4 months old. One plot incorporated 150 seedlings of *L. leucocephala*, 149 seedlings of *Eucalyptus tereticornis*, 62 seedlings of *Casuarina equisetifolia*, 25 of *Erythrina indica*, and 10 of *Gliricidia sepium*. The other was planted with 395 leucaena seedlings (Table 2). In the polyculture plot, *E. tereticornis* has shown the best growth, with *L. leucocephala* next. *Gliricidia sepium* has grown well, with *C. equisetifolia* growing more slowly, but, being heavier wood, the latter will fetch a better price. Performance of *L. leucocephala* was better in monoculture than in polyculture; however, polyculture gave a slightly higher total biomass. In both plots, pruning was done in February and May, and the trees were ready for pruning again in July. In polyculture, pruning was done only once for *E. tereticornis*. Our studies have indicated that pruning every quarter is essential for healthy increment in biomass in both systems. We shall study these plots for at least another 2 years, but, based on a year's observation, we feel that *L. leucocephala*, *E. tereticornis*, and *C. equisetifolia* are a good combination for polyculture.

Foliar versus Root Irrigation

Trials were conducted on two plots, each 350 m^2, in which 90 seedlings (2 m × 2 m) were planted. Irrigation of one plot was done by a hose placed at the base of each tree every 4 days; the total at each watering was 300 L. A sprinkler was used for the other plot, every 4 days. The sprinkler was placed 6 m above ground and turned on for 3 min at nine places for a total 300 L per irrigation. Data on biomass production indicated that foliar irrigation produced much better foliage and wood than did irrigation at the base of the tree (Table 3). Total biomass in 6 months, extrapolated to a per-hectare basis, was 9.35 t for root irrigation and 16.9 t for foliar irrigation. On a dry-weight basis, these figures are equal to 4.9 t and 8.4 t, respectively.

In January 1982, 12 *Piper betel* and 25 *P. nigrum* seedlings were transplanted in each of these two plots as an understory. By April

Table 2. Biomass yields from polyculture and monoculture plots incorporating leucaena.

	Yield (kg/tree, wet basis)			Extrapolated yield (kg/ha, wet basis)		
	Foliage	Wood	Total biomass	Foliage	Wood	Total biomass
Polyculture						
L. leucocephala	0.40	0.85	1.25	1519	3228	4747
E. tereticornis	0.75	1.50	2.25	2810	5620	8430
C. equisetifolia	0.20	1.00	1.20	314	1569	1883
G. sepium	0.40	0.60	1.00	101	253	352
E. indica	0.30	1.00	1.30	189.6	632	821
Monoculture						
L. leucocephala	0.50	1.10	1.60	5000	11000	16000

Table 3. Growth and biomass of leucaena in plots with root or foliar irrigation.

	Root irrigation			Foliar irrigation		
	Biomass, 12/81	Pruning, 5/82	Biomass, 6/82	Biomass, 12/81	Pruning, 5/82	Biomass, 6/82
Average height (m)	5.8	—	7	6	—	7.25
Average girth (cm)	19		23	21		25
Biomass (kg/tree)						
Foliage	0.675	—	1.1	0.720	—	2.25
Wood	3.000	—	4.9	3.50	—	7.50
Pruning (kg/plot)						
Foliage	—	50	—	—	68	—
Wood	—	40	—	—	50	—
Biomass (kg/ha)						
Foliage	1735	1428.5	2828	1851	1942.8	5625
Wood	7715	1142.0	12600	9000	1428.5	18750

1982, most of the understory plants in the basally irrigated plot had begun to wither, and, by May, 35 plants of the 37 had died. In the foliar-irrigation plot, all the understory has continued to grow well because the sprinkler irrigation produced thick crowns on the trees. In other words, foliar irrigation helps significantly to increase biomass and sustains a healthy understory.

Layering Technique

We sucessfully tissue layered 150 *C. equisetifolia*, 60 *G. sepium*, and 100 *L. leucocephala* plants, and this success should prove useful to our proposed large-scale afforestation project.

Animal-Feed Trials

Shade-dried (so that colour was retained), pulverized leucaena foliage was fed to five lactating cows and buffaloes on the cattle farm of Sadanand Joshi at Kalyan during January–June 1982. The experiments were jointly supervised by our team and S.R. Vaidya of the Maharashtra State Animal Husbandry Department, Kalyan. Leucaena feed (10–15% moisture) was given to cows and buffaloes as a 10% additive to 90% standard balanced pellets.[2] The five control cows and buffaloes were given 100% standard balanced pellets. Within 1 month, leucaena-fed cows and buffaloes increased their milk yield by more than 20%. During the trials, there was incidence of foot-and-mouth disease in March, and most of the control cattle lost their appetite, with one result being decreased milk yield. The leucaena-fed cattle, however, continued to eat normally, and their milk yield was maintained. We concluded that, at 10% of the diet, leucaena was not harmful to the cattle. Instead, it provided balanced nutrition so that, even under stress conditions, the cattle were healthy. These findings may reflect carotenoid and xanthophyll pigments present in leucaena foliage that may be an antidote to foot-and-mouth disease. Double-blind trials have not yet been performed.

Feeding trials with 1600 chicks were done from January to June 1982 at the broiler farm of R.C. Chowdhary in Ambarnath. The 800 controls were given a standard diet[1] made by Godrej and Co., and the other chicks received 95% standard balanced feed and 5% pulverized, shade-dried leucaena foliage. Weights were recorded every week. There was a 15–20% net weight increase at the end of 8 weeks in the treated chicks. A separate experiment was conducted on chicks affected by coccidiesis followed by fowl-pox. In this experiment, the chicks were fed 85% standard balanced feed plus 15% pulverized leucaena feed. Within a week, the disease had totally disappeared. The controls became extremely weak and had to be given antibiotics. Feeding the diseased chicks a diet with 15% leucaena saved Rs 0.75–1/chick (US$ 1 = Rs 9.62) over 6–8 weeks.

[2] Composition of standard balanced pellets is moisture 10–11%, crude fat 3–3.5%, crude protein 22%, fibre 10–12%, acid-insoluble ash 3–3.5%, and fillers 48–52%.

[3] Standard balanced composition of poultry feed is protein 38%, fat 2%, fibre 6%, acid-insoluble ash 4%, lysine 2%, methionine and cystine 1.1%, calcium 2.5%, phosphorus 1% (metabolizable energy 2500 kcal/kg), and fillers 43–44%.

Leucaena leucocephala as a Tall Cover Crop for Sawlog Plantations

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Leucaena leucocephala *seldom exceeds 20 m high and usually stops growing at 15 m or less in most sites in Malaysia. Hence, it is too small to be a sawlog species. However, because it is fast growing, it may play a useful role as a tall cover crop in sawlog plantations where the sawlog species is expected to grow to 30 m or more. Preliminary results of trials with* L. leucocephala *as a cover crop for teak and* Araucaria sp. *have proved promising.*

Leucaena leucocephala *dépasse rarement 20 m de hauteur et sa croissance s'arrête généralement à 15 m ou moins dans la plupart des régions de la Malaisie. Il est donc trop peu important comme bois de sciage. Cependant, comme il pousse rapidement, il peut être utile comme haute formation végétale de couverture pour de jeunes peuplements d'espèces destinées au sciage et dont la hauteur pourra atteindre 30 m ou plus. Des premiers essais utilisant* L. leucocephala *comme couverture pour le teck et* Araucaria *se sont révélés prometteurs.*

La Leucaena leucocephala *raramente excede 20 m de alto y generalmente se detiene a los 15 ó menos en la mayor parte de Malasia. Por tanto, es demasiado pequeña para ser una especie de aserrío. Sin embargo, como es de crecimiento rápido, puede desempeñar una función útil como cobertura alta en las plantaciones de madera de aserrío, donde se espera que las especies crezcan 30 m ó más. Resultados preliminares de las pruebas con* L. leucocephala *como sombrío para la teca y la* Araucaria *han sido promisorios.*

Monospecific vegetation is more unnatural in the humid tropics than anywhere else in the world, and to maintain nonspecific tree plantations requires the continual input of energy in the form of labour, herbicides, and pesticides. Any relaxation results in weed invasion and proliferation.

Although the effects of weeds are not all negative — for example, they help to protect the soil from exposure and degradation wherever the crop itself fails to form a protective cover — they often compete and suppress crops because of their greater vigour and better adaptation to a site.

One way to minimize weeds, maximize crop production, and simultaneously to provide cover is to plant at very close spacing. Then, the crop can utilize space, soil resources, and sunlight. This approach is widely adopted for short-rotation crops such as rice. Nevertheless, one species cannot be planted repeatedly on the same site without a steep decline in yield. Such decline is usually attributed to selective exhaustion of nutrients by the species concerned and to buildup of pathogens of that species. Hence short-rotation crops are usually grown in sequence with one or more other species, of which one is usually a nitrogen-fixing legume.

For long-rotation crops, such as trees, however, close planting and sequential cropping cannot be practiced for two reasons. First, the space requirements of a healthy tree increase each year until maturity, and a mature tree is enormous compared with its seedling. Hence, there is no single spacing that is suitable for the whole economic life of a monospecific tree plantation. Second, a long-lived crop may suffer from soil exhaustion and pathogen buildup before it is due to be rotated with another species.

Two different approaches to solving the problem can be seen in Malaysian arboriculture. One is traditional, characterized by multispecies composition, multistoried canopy structure, and uneven-aged trees. Such arboriculture, mostly of fruit trees, has endured for centuries without the application of modern pesticides and chemical fertilizers and without intensive labour. The multistoried canopy reduces the light at ground level to an intensity too low for the more aggressive weeds to thrive. The multispecies composition, and individual replacement of old trees by young ones through underplanting, effectively substitutes for crop rotation.

Traditional arboriculture produces a multiplicity of products in a diffused manner. Modern arboriculture, as exemplified by rubber,

oil-palm, and cocoa plantations in Malaysia, however, is industrial, geared to producing a single product. The conveyor belt may not be a part of the operation, but the conveyor-belt concept is very much in evidence. The trees are planted at the same age, in a uniform spacing designed to accommodate mature trees, with plenty of space for weed proliferation until the trees achieve canopy closure. Weeds are preempted, however, by the deliberate cultivation of a legume species to provide cover. The modern rubber or oil-palm plantation is, therefore, not truly monospecific. It is a two-species association — a tree with a leguminous herb. Although the legume component is normally referred to as the "cover crop," the relationship between the two components is dynamic, with the legume playing the main cover role in the beginning, gradually being phased out under the shade of the growing trees, and disappearing when the trees form a closed canopy. At the final stage, the trees provide the main cover, and the legume is naturally succeeded by shade-tolerant vegetation, among which are herbs, shrubs, as well as juvenile trees. The producers systematically eliminate shrubs and juvenile trees mechanically or by poisoning so as to prevent reversion to forestlike conditions.

Crop-Management Concepts in Silviculture

Natural tropical forests are multispecific, multilayered, and uneven-aged in composition. The multiple and highly varied products from such forests do not lend themselves easily to standardized procedures in harvesting, processing, promotion, marketing, or utilization. Monospecific timber plantations, therefore, have a great deal of attraction, particularly when linked to the promise of higher growth rates and shorter rotation times. Hence, most tropical forestry organizations have experimented with monospecific plantations, and some have launched ambitious plantation schemes.

In practice, there are two different approaches to the establishment of tropical timber plantations. The first approach is underplanting within logged-over forests. After the removal of commercial timber trees, a considerable amount of vegetation is left. Underplanting involves opening lines or gaps in such logged-over forests and planting seedlings of particular species, either in single lines or in clusters. The existing natural vegetation is cleared only enough to allow overhead light to reach the planted seedlings; the bulk of existing vegetation is left as a "matrix" that serves as a cover to protect the soil, as a nurse to provide some shade for the planted seedlings, and as a "filler" to provide a certain amount of crowding so that the planted seedlings are forced to elongate and produce 1–3 log lengths of clear bole before spreading their crown. The major difference between a plantation for sawn timber and other plantations is the emphasis on the development of a long clear bole, which is the final product and main objective of management.

In other words, timber plantations require a different sort of cover crop — one that simultaneously protects the soil between the planted timber trees, provides the necessary degree of crowding to stimulate vertical growth, provides partial shade for optimum growth of timber species in the juvenile stages, and suppresses weeds without itself being a weed. We refer to this sort of cover crop as a tall cover to differentiate it from the groundcover that is normally associated with the cover-crop concept.

The management of a tall cover provided by natural vegetation in logged-over forests is not easy because neither the height of the cover nor the density of foliage is uniform. As a result, the size of the clearing to be made around the planted seedlings is usually decided arbitrarily, the intention being that overshadowing will be prevented by periodic cleaning and clearing operations. The real drawback in this approach derives from the fact that the timber species best suited for such management have rotations of 50–80 years, according to silvicultural studies (Wyatt-Smith 1963). This is considered too long for conventional economic planning and investment.

One means to satisfy all the requirements is to plant fast-growing timber species. These are usually species with pioneer characteristics that establish on open ground. The pioneer species suitable for timber plantations are the giants such as *Tectona grandis*, *Gmelina arborea*, *Pinus caribbaea*, *Eucalyptus* spp., *Albizia falcataria*, and *Acacia mangium*. For sawlog production, a straight cylindrical bole of low taper is preferred. Having cleared the land to plant such species, one must still provide cover for the land, control weeds, and provide for controlled crowding. The traditional practice in monocultural timber plantations is to plant

close and to thin the crop in stages. In other words, the crop species is expected simultaneously to cover the soil, shade out weeds, provide mutual crowding, and produce timber. Is this realistic? Trials on spacing requirements suggest that it is not. Numerous trials have been carried out to determine the optimum spacing for each timber species, but the results have nearly always been inconclusive.

To provide cover from the start, the trees must be so close together that the number of seedlings planted far exceeds the number of mature trees in the final crop. For example, square spacing, starting at 1 m × 1 m and ending with crop maturity at 8 m × 8 m, would involve 10 000 seedlings/ha, thinned progressively to 156 trees/ha. This enormous rate of attrition, although planned and deliberate, puts tremendous strain on any stock-production program and discourages the wider use of expensive, genetically improved stock. Furthermore, there is a fundamental contradiction because genetic improvement for timber trees involves selection for early development of clear bole at the expense of lateral branching, thereby reducing the ability of such trees to act as a cover. Compromise spacings using 2 m × 2 m (2500 seedlings/ha) or 3 m × 3 m (1111/ha) at the start open the way for weed proliferation in the critical early years of plantation establishment, and the trees still need to be thinned.

The solution to the problem appears to lie in separation of functions. The timber species should be selected and managed for timber production. Other species should be selected and managed as the cover crop. The acceptance of this solution would clear the way for specification and testing of tall cover crops (Ng 1980).

Specifications for a Tall Cover Crop

The principles for improving a timber tree are well known, but those for a tall cover crop need to be defined. One property that would be essential is low-cost seeds, seedlings, and establishment compared with the timber species. The species should also be able to:

- Establish under the same ecological conditions as the timber crop so that the two can be planted together;
- Shade out light-demanding weeds and provide cover for soil without suppressing the timber species;
- Grow to the required clear-bole height of the timber species but not taller;
- Improve soil, e.g., by fixing nitrogen; and
- Produce only small, easily decomposed, litter.

Other features are that it should not be able to tolerate shade so that it dies when outgrown by the timber species, and it should have no allelopathic or other inhibitory effect on the timber species.

One crop that was considered to have many of these characteristics is *Leucaena leucocephala*, so it was selected for trials as a tall cover crop with teak and araucaria in Malaysia.

Leucaena for Teak Plantations

In May 1980, 9.4 ha of teak and leucaena were planted in Mata Ayer Forest Reserve in the state of Perlis, Malaysia. The land was flat, low-lying (ca 50 m above sea level), and covered with early secondary growth, including *Imperata*, bamboos, and various herbaceous and shrubby weeds. The vegetation was slashed, the area plowed, and the teak planted at a spacing of 3 m × 3 m in the form of stumps (cleaned taproot topped by 1–2 cm stem). Hence, new shoot growth had to start from the ground. Leucaena seedlings (about 0.5 m tall) in containers were planted at the same spacing as the teak but alternated with it (Fig. 1). The minimum distance between plants (teak and leucaena taken together) was 2.12 m. Five sample plots, A–E, were laid out in different parts of the area so that growth could be monitored. Each plot was square and consisted of 6 × 6 teak trees and 7 × 7 leucaena trees. The trees were measured in October 1982, 29 months after establishment.

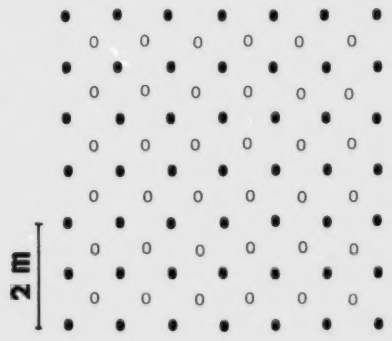

Fig. 1. Planting spacing for teak (○) and leucaena (●).

Table 1. Growth of *T. grandis* and *L. leucocephala* in mixed planting after 29 months.

	Plot				
	A	B	C	D	E
Teak					
Seedlings planted	36	36	36	36	36
Surviving plants	33	33	31	32	11
Mean height (m)	9.04	3.36	3.45	0.50	1.01
Standard deviation (height)	3.09	2.25	1.60	0.32	0.90
Leucaena					
Seedlings planted	49	49	49	49	49
Surviving plants	42	45	44	47	27
Mean height (m)	9.43	6.72	4.91	4.54	3.83
Standard deviation (height)	2.29	1.72	1.42	1.08	1.19

The height of teak (Table 1) indicated that site quality was extremely variable. On the best site, plot A, the teak and leucaena were about evenly matched in height and averaged slightly more than 9 m tall. In the other four plots, the performance of both species was depressed. Leucaena always outperformed teak, and the discrepancy between them was greatest where the teak performed worst. We concluded that site quality rather than incompatibility between the two species was responsible for the depression because both species performed poorly on some sites and well on others.

The ability of the teak–leucaena combination to control weeds was not as good as hoped. On the best site (plot A), *Imperata* was effectively suppressed but, elsewhere, was still very much in evidence, although probably weakening in plots B and C. The worst weed was the legume twiner *Pueraria* sp., ironically introduced into the area in an earlier cover-crop experiment and now forming a doubly vicious weed association with *Imperata*. By climbing, smothering, and strangling, *Pueraria* can destroy any plants that manage to outgrow the *Imperata*. To survive, the saplings must be freed from *Pueraria* frequently.

Leucaena for Araucaria Plantations

Next to teak, the most highly regarded species for timber plantations in Malaysia is *Araucaria hunsteinii*. Seeds are imported from Papua New Guinea and are not only expensive but also in very short supply. Conventional close planting and thinning would be unthinkable for such a species.

In a small experiment in Sungei Buloh, near our Institute at Kepong, seedlings of *A. hunsteinii*, about 0.75 m tall, were planted at 3 m × 3 m spacing in October 1980, on low-lying (30–46 m above sea level) land that had a history of food-crop cultivation, cattle grazing, burning, and *Imperata* infestation. Seedlings of *L. leucocephala*, about the same height as the araucaria, were interplanted with the latter in three different intensities (Fig. 2) such that the ratio of araucaria to leucaena was 1 : 1; 1 : 2; and 2 : 1. Three rectangular plots of 9 × 4 araucaria trees were demarcated, and measurements were made in October 1982, at age 2 years (Table 2).

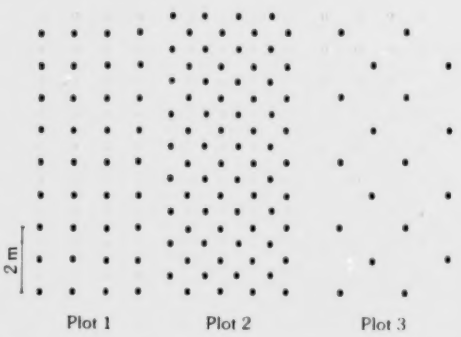

Fig. 2. Planting spacings for araucaria ( ) and leucaena (•).

The leucaena was always taller than the araucaria. Plot 3, with plants at the lowest density, produced the worst growth for araucaria but best growth for leucaena. The most favourable planting design for araucaria was that of plot 1, which had the advantages of producing good growth in both araucaria and leucaena, having a neat appearance, and being lower in cost of planting than plot 2.

Imperata was effectively checked in all three plots, but several species of cover-crop legumes were introduced as seeds into the

Table 2. Growth of *A. hunsteinii* and *L. leucocephala* in mixed planting after 24 months.

	Plot		
	1	2	3
Araucaria			
Seedlings planted	36	36	36
Surviving plants	26	30	24
Mean height (m)	2.06	1.92	1.62
Standard deviation (height)	0.56	0.49	0.46
Leucaena			
Seedlings planted	36	72	18
Surviving plants	28	42	11
Mean height (m)	4.60	3.57	6.05
Standard deviation (height)	0.84	0.96	1.97

plots in January 1981. These were *Pueraria phaseoloides*, *Centrosema pubescens*, *Calopogonium caeruleum*, *C. mucunoides*, and *Stylosanthes gracilis*. By October 1982, the *Stylosanthes*, a small erect herb, had virtually disappeared, but the others, especially *Pueraria* and *Centrosema*, had become serious weeds, requiring frequent cutting and threatening to strangle and smother the araucaria and leucaena.

Auraucaria – leucaena interplanting trial in Sungei Buloh Forest Reserve, Selangor, at 24 months.

Discussion

Although the experiments have not yet been completed, we can begin to assess the potential of leucaena as a tall cover crop for timber plantations, according to our list of specifications:

- Leucaena trees produce seed prolifically; the seeds are easy to harvest, store, transport, and germinate. Seedlings are easily raised and planted out. The cost per seedling planted is a fraction of the cost for teak and araucaria.
- Leucaena prefers open conditions and can be established together with other fast-growing, light-demanding species.
- Leucaena has a diffuse canopy that does not appear to inhibit teak or araucaria. On good sites, the teak–leucaena combination suppresses *Imperata* within 2 years. On poor sites, this combination is rather ineffective at the spacing used (ca 2 m between plants) because of depressed crown development in both species; juvenile and stunted teak, because of its unbranched, or sparsely branched habit, is particularly ineffective in providing cover. The araucaria–leucaena combination casts denser shade and is better at *Imperata* suppression because araucaria bears multiple tiers of branch foliage.
- Other observations (Norani and Ng 1981) indicate that leucaena is very variable in height, depending on site conditions. To be useful as a tall cover crop, it must reach a minimum of 10 m. This has not yet been achieved in 29 months.
- As for being self-limiting in height, leucaena is unlikely to exceed 15 m under most Malaysian site conditions.
- The gradual elimination of leucaena by teak or araucaria has not yet happened in our 24–29-month-old trials but may be expected within 5 years of plantation establishment, depending on site conditions.
- The nitrogen-fixing ability of leucaena is already recognized.
- Leucaena produces the finest and most easily decomposed leaf litter that can be expected.
- And it does not appear to have an inhibitory effect on either teak or araucaria.

Another possible specification for a tall cover crop is the ability to produce an economic product in its own right, e.g., fuelwood, food, fodder, etc. Such a specification would lead into agroforestry, which is not the subject of this paper. Nevertheless, leucaena also conforms to this criterion.

We have not focused on the potential agroforestry applications because, in Malaysia, the need for multiple products is less great than the need to protect plantation silviculture from the dangers inherent in monoculture (exemplified in *Gmelina* cultivation in Brazil and *P. caribbaea* in Malaysia).

We think that the promise of faster economic returns from plantation forestry cannot be realized without a strong genetic program to produce superior stock, coupled with ecologically sensible management of soil and space. As genetically superior plants should not be used wastefully and as monoculture involves high maintenance costs because of its ecological disequilibrium, it follows that the initial spacing of timber trees should be as close to final spacing as possible and that unutilized space should be densely planted with a suitable tall cover. Leucaena may or may not prove ultimately to be the tall cover that is needed, but the search needs to be continued.

Research on Leucaena Wood at the Forest Products Research and Development Institute (FPRDI), Philippines

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The Forest Products Research and Development Institute got involved in research on the utilization of wood from giant leucaena in 1973 in response to the need expressed by several wood-industry companies and entrepreneurs. This paper presents some of the results of studies on proximate chemical composition; specific gravity and calorific value; fibre morphology; mechanical properties; lumber recovery; parquet flooring; kiln drying of lumber and poles; preservative treatments; particleboard; hardboard; dissolving pulp; paper pulp; charcoal; and fuelwood for dendrothermal power plants.

L'Institut de recherches et de développement des produits forestiers (FPRDI) a entrepris, en 1973, des études sur l'utilisation du bois de Leucaena *géant pour répondre aux demandes de plusieurs membres et entrepreneurs de l'industrie du bois. Cet exposé rapporte divers résultats d'études sur les sujets suivants : composition chimique approximative du bois ; poids spécifique et valeur calorifique ; morphologie de la fibre, propriétés mécaniques, proportions de bois de construction, parquets en bois, séchage au four du bois d'oeuvre et des poteaux, panneaux de particules ; panneaux de fibres durs ; traitement de préservation ; pâte à dissoudre ; pâte à papier ; charbon de bois ; et bois de chauffage pour les centrales dendrothermiques.*

El Instituto de Investigación y Desarrollo de Productos Forestales (FPRDI) se involucró en la investigación sobre utilización de madera de Leucaena *gigante en 1973 como respuesta a la necesidad expresada por varias industrias madereras. Este trabajo presenta algunos resultados de los estudios sobre composición química proximal, gravedad específica y valor calórico, morfología de la fibra, propiedades mecánicas, recuperación de maderos, pisos de plaquetas, secado en horno de maderos y postes, tratamientos de preservación láminas prensadas, disolución de pulpa, pulpa de papel, carbón y combustible para plantas de energía dendrotérmica.*

The Forest Products Research and Development Institute (FPRDI) began researching the utilization of giant *Leucaena leucocephala* (locally called ipil-ipil) in 1973 in response to requests by several wood-industry companies and entrepreneurs. Subsequently, financial assistance was provided by the National Science and Technology Authority (NSTA) and the Philippine Council for Agriculture and Resources Research (PCARR). This paper presents some results of the research.

Wood Properties

Escolano et al. (1978) analyzed the chemical composition of seven samples of giant leucaena from different sources, as well as that for the native leucaena and the Philippine mahogany group (average of seven species). The ranges for the giant leucaena samples were 69.8–73.9% holecellulose, 8.9–20.1% pentosans; 21.8–26.0% lignin; 13.0–16.4% caustic soda solubles; and 0.7–0.9% ash. These data indicate that the giant leucaenas (Peru and K28) would be better raw material for pulp-and-paper manufacture than the Philippine mahogany woods or the native leucaena.

Laxamana (1981) tested the specific-gravity and heating values for the wood of seven varieties of giant leucaena and reported that a 5-year-old Peru variety had the highest (0.665) specific gravity and a 1-year-old K28 had the lowest (0.379). As K28 matures, however, its specific gravity increases: 0.518 at 2 years; 0.569 at 4–5 years; and 0.634 at 6 years. In comparison, the native variety has a specific gravity of 0.73 (Rocafort et al. 1971).

The heating values of the seven varieties ranged from 4.0 kcal/g in a 2-year-old K28 to 4.3 kcal/g in a 2.5-year-old Mexican variety. Apparently, the common variety also has a higher heating value (4.6–4.7 kcal/g) than the giant varieties (Aguilar 1943).

The fibre dimensions of giant and native leucaena were reported by Tamolang et al. (1957). The values are typical of those of hardwoods and are within the ranges for those obtained for various Philippine hardwoods. The average fibres of the giant samples are longer than those of the native leucaena but

shorter than those of Philippine mahogany species.

Standard tests of the mechanical properties of leucaena were reported by Floresca et al. (1978). The tests were done on green, clear specimens taken from two trees of giant leucaena with average diameters of 18 cm and 15 cm at the butt and top portions, respectively, and about 549 cm long. These trees were obtained from Canlubang, Laguna. The results were compared with the strength properties of seven Philippine mahogany (PM) species, which are commonly used for stonecut sidings and tongue-and-groove flooring, and with those for seven species of *Dipterocarpus*, or apitong group, most commonly used for rafters and roof trusses. The findings were that:

- The strength properties of giant leucaena exceeded those of tiaong (*Shorea agsaboensis*), the weakest PM species in every measurement except modulus of elasticity in compression parallel to the green (85% of that for tiaong). Compared with bagtikan (*Parashorea plicata*), the strongest of PM species, the leucaena was inferior in all strength properties.
- Compared with the weakest of the apitong group (*D. warburgi*), leucaena was inferior in strength properties, i.e., 79% for modulus of elasticity in bending, 99% for stress at proportional limit in compression, and 70% for modulus of elasticity in compression. Compared with the strongest of the apitong group (*D. grandiflora*), it was inferior in all properties except compression perpendicular to the grain, hardness, and shear.

As the study on strength properties of giant leucaena was conducted on only two trees obtained from Canlubang, Laguna, the authors (Floresca et al. 1978) considered the findings as tentative but considered the strength properties of giant leucaena, in this particular case, as comparable with some species of both *Dipterocarpus* and Philippine mahogany.

Potential Uses

Studies on giant leucaena conducted at FPRDI, using the 1300-mm bandmill with a gauge-16 blade with stellite-tipped teeth, showed lumber recoveries of 56% and 61% from 5-year-old and 7-year-old trees, respectively, from Canlubang, Calamba, Laguna (Eala and Ortiz 1978). The five logs (diameter 22–25 cm, 1.52–1.89 m long) from the 7-year-old trees were sawn into a nominal thickness of 2.54 cm and various widths. The recovery figures were lower than those obtained by commercial bandmills in Metro Manila at 68% of log volumes (Decena et al. 1970), probably because the bandmills were processing larger logs.

Using wood hardness and shrinkage behaviour as suitability indicators for parquet flooring material, Eala and Salita (1981) reported that giant-leucaena wood appeared to be comparable with the traditional species (*Pterocarpus indicus*, *Shorea polysperma*, and *S. guisok*) being used (Table 1). One cubic metre of logs (input) of 4-year-old giant leucaena trees produced 22 m^2 of parquet materials (fillets of 2.54 cm × 12.7 cm × 1 cm).

Drying of 25- and 50-mm thick giant leucaena lumber and round poles was investigated under various drying methods by Laxamana (1981) who found that both K28 and the Peru variety were relatively easy to season. Predrying either in the sun or by forced air mechanisms shortened kiln-residence time, thus saving energy as well as producing better-quality dried materials.

Barrel check, along the round pole surface, warping, and surface checks in some 50-mm thick sawn boards occurred in kiln drying. These defects could be minimized by careful, slow drying.

Table 1. Suitability of four woods as parquet material.

	Hardness (kg)		Specific gravity	Shrinkage (%)			
				Radial		Tangential	
	End	Side		G-12	G-OD	G-12	G-OD
L. leucocephala	815	710	0.62	2.4	4.8	5.0	8.4
P. indicus	446	423	0.53	0.9	2.7	1.4	4.0
S. polysperma	260	262	0.44	2.0	3.6	4.0	7.6
S. guisok	854	682	0.80	2.8	5.9	6.0	10.4

Three varieties of leucaena, K28, K8, and Peru, were given five preservative treatments, and the results were reported by Siriban et al. (1981).

In the first treatment, specimens measuring 50 mm × 76 mm × 460 mm with an average moisture content of 78.6% were brushed with 30% boron-flouride-chromium-arsenic (BFCA) solution, wrapped in polyethylene bags, and left for 1, 2, and 3 weeks.

Tests showed an average penetration of 2.8 mm in the 2- and 3-week diffusion periods. The heartwood was totally unpenetrated. The extent of penetration was considered sufficient to protect the specimens from insect infestation and decay.

In the second treatment, specimens were immersed in a tank containing 8% copper sulfate for 7 days and then transferred to another tank with 8% potassium dichromate for another 7 days. Results showed a penetration 9 mm deep in the sapwood — a depth that was considered sufficient to protect lumber not exposed to weather.

The third treatment was a hot-and-cold bath. Specimens were heated in a bath of 50 : 50 creosote – bunker-oil solution for 2, 4, and 6 h at 100°C and then subjected to a cold-bath treatment for 2, 4 h, or overnight. Specimens hot-bathed for 2 h and cooled for 2 h had an average side penetration of 4 mm. Prolonged hot-and-cold bath treatments did not produce as satisfactory penetration as did the other treatments.

Specimens in the fourth treatment, i.e., pressure treatment — full-cell process — showed that the heartwood is moderately difficult to treat and the sapwood easy to treat, with an average retention of 314 kg/m³. The green sapwood was especially easily and effectively treated by high-pressure sap displacement, the fifth treatment, with retentions that were much better than those for conventional pressure treatments.

Pablo et al. (1981) reported that giant leucaena particleboard, comparable with that from other medium-density species tested at FPRDI, could be made from both debarked and partially degraded leucaena logs (Table 2). When resin content was increased from 8% to 9% and the particle size increased to 0.62 mm, the properties of the particleboard prepared from partially degraded logs were improved.

A more recent study (Generalla 1982) showed that, at 8% resin content, density of fine-surfaced boards would have to be 0.7 g/cm³ and 0.6 g/cm³ at bending strength of >180 kg/cm² and 130–180 kg/cm² respectively, whereas, for flake-type homogeneous boards with bending strength of >180 kg/cm² and 130–180 kg/cm², the density would have to be 0.65 g/cm³ and 0.60 g/cm³, respectively.

Table 2. Average mechanical and physical properties of urea-formaldehyde-bonded giant leucaena particleboards (density 650 kg/cm³).

	Good-quality chips[a]	Low-quality chips[b]
Chip thickness (mm)	0.33	0.62
Resin content (%)	8	9
Modulus of rupture (kg/cm²)	171	176
Internal bond (kg/cm²)	4.7	4.3
Thickness swelling (%)	26	16

[a] From freshly felled, debarked material.
[b] From partially degraded materials with bark.

In 1975, Semana and Lasmarias reported a study of hardboard from 2.5-year-old leucaena (average length of trunk 5.2 m, average diameter at butt 14.4 cm, specific gravity 0.59) from Davao City. The wet process was used to convert the wood to hardboard; pulping was done in a laboratory Asplund defibrator (yield 94.2%) and then processed in a disc refiner to a freeness of 24.0 seconds (defibrator seconds).

The authors concluded that the hardboards from the Peru variety could meet the specifications for US standard-type hardboards and would be equal in quality with the ones produced locally from other species.

Inciong et al. (1978) tested giant leucaena wood in the production of dissolving pulp, incorporating both debarked and barked samples in the study. Their results indicated that water prehydrolysis (first stage) and kraft pulping (second stage) at 15.60 and 18.22% active alkali and 25% sulfidity produced easily bleachable chemical pulp from the leucaena. Alpha-cellulose content was high (92.08–96.68%), and yield ranged from 35.33% to 46.02%. However, the multistage bleaching processes that were employed in this study proved to be ineffective, resulting in reduced alpha-cellulose content. An earlier study (Bawagan and Villanueva 1976) had found that a five-step bleaching process — chlorination, alkali extraction, addition of hypochlorite, alkali extraction, and addition of chlorine dioxide — was effective, but this process was not tested by Inciong et al. (1978).

Kraft-pulping studies are being conducted by Semana et al. (1981a,b) on 1- and 2-year-old K8, K28, K67, Peru, and COPIL varieties of leucaena. Screened pulp yields have ranged from 49.5% to 50.6% for the 1-year-old stems and from 48.6% to 50.5% for the 2-year-old stems. These values compare favourably with those obtained from other reforestation species like *Anthocephalus chinensis* and Moluccan sau, although strength properties of the pulp handsheets were slightly inferior, notably in tensile strength. Of the five strains, K8 and K28 exhibited the best strength properties.

Fuel

I (1982) have recently reported studies of charcoal production from giant leucaena wood. The 2-year charcoaling operation was conducted in four beehive oven prototypes that were being compared in the study. (One of the prototypes — the one developed by FPRDI staff — is now being used commercially to produce charcoal from sawmill waste and giant leucaena.) The data collected were the volume of wood charge, charcoaling cycle time, the volume and weight of charcoal produced per cycle, and charcoal yield. The proximate chemical composition of the charcoal produced showed 79.5–84.7% fixed carbon and 10.8–17.5% volatile matter.

The technical and economic feasibility of using plantations of giant leucaena and other fast-growing wood species for wood-fired, steam power plants was studied by FPRDI from 1974 to 1979 (Semana et al. 1977; Bawagan and Semana 1979, 1980; Semana and Bawagan 1979). The findings were that, at crude-oil costs of US$ 18 barrel, the production cost of a 75-MW, oil-fired steam power plant would be US$ 0.038/net kWh compared with US$ 0.026–0.074/kWh for dendrothermal steam-powered plants of 10–75-MW capacity. At a higher cost of oil (US$ 37/barrel), even a 10-MW, wood-fired plant would be competitive with the 75-MW, oil-fired plant. It was shown, further, under Philippine conditions, that combining a dendrothermal power plant with fuelwood plantation would be better than operating an oil-fired power plant because of the employment generated and foreign-exchange conserved. The National Electrification Administration (1982) has announced commercial power-generation programs for 1982–87, resulting in a total capacity of 200 MW.

Plans are for 7.0×10^4 ha to be reforested, 11 000 jobs created, 60–70 power plants constructed from foreign (US$ 220 million) and local funding (US$ 120 million). A yearly saving of 1.75 million barrels of oil-energy equivalent is expected. To the year 2000, the target is 2000 MW of electricity-generation capacity from fuelwood, the corresponding land area to be reforested being 7.0×10^5 ha.

Conclusions

Basic information on leucaena wood such as the proximate chemical composition, specific gravity, calorific value, fibre morphology, and mechanical properties provides some indication of potential uses but should be validated. FPRDI has undertaken some of the necessary tests, examining lumber recovery, parquet flooring, drying of lumber and poles, preservative treatment, particleboard, hardboard, dissolving pulp, paper pulp, and charcoal. The question of which among these various possible uses of leucaena wood is most promising in terms of profitability, investment requirements, and economy of scale for commercialization in a given set of conditions has yet to be answered and should be the subject of a comprehensive feasibility study.

Introduction and Trial Planting of Leucaena in China[1]

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Salvador-type leucaena is a tropical crop with potential use as a high-protein animal feed, highly effective manure, high-energy fuelwood, and fast-growing timber. It is an ideal and much-needed tree species for south China's agriculture, forestry, and animal-husbandry operations and will play a part in their integration. Although a tropical plant, leucaena can also grow in the subtropical regions. Its optimal growing area is considered to be the region to the south of the Tropic of Cancer (23°30'N). It is adapted to coastal plains and hills, and it grows best on well-drained, deep, neutral, sandy loam of above-average fertility. It can also thrive on soils with a pH of 5.5–8, but, on soils with a pH below this level, it performs unsatisfactorily.

Le Leucaena de type Salvador offre de bonnes possibilités comme récolte tropicale aux produits utilisables soit comme aliment protéique du bétail, soit comme un excellent engrais vert, ou encore comme bois de chauffage ou de construction à croissance rapide. C'est une espèce d'arbre idéale, et dont la Chine méridionale a grand besoin, pour son agriculture, ses forêts et son élevage auxquels il est appelé à s'intégrer. Bien que d'abord une plante tropicale, Leucaena prospère également dans la zone subtropicale, et les régions où il croît le mieux sont situées au sud du tropique de Cancer (23°30'N). Il s'adapte aux plaines et aux collines côtières ; les terres franches sablonneuses bien égouttées, profondes et neutres, plus fertiles que la moyenne lui conviennent particulièrement. Il réussit bien également dans des sols au pH compris entre 5,5 et 8, mais non dans ceux dont le pH est inférieur à ces chiffres.

La leucaena tipo Salvador es un cultivo tropical con uso potencial como alimento animal de elevado contenido protéico, abono de gran efectividad, combustible de alta energía y madera de rápido crecimiento. Esta es una especie arbórea ideal y necesaria para la agricultura, la forestación y las operaciones de producción animal en el sur de China y jugará un buen papel en su integración. Aunque tropical, la leucaena también puede crecer en las regiones subtropicales. Se considera que su área óptima de crecimiento es la región al sur del Trópico de Cáncer (23°30'N). Se adapta a las planicies y colinas costeras, y crece mejor en suelos arenosos, bien drenados, profundos, neutros y con una fertilidad por encima del promedio. También puede crecer en suelos con un pH de 5,5–8, pero en suelos con pH por debajo de este nivel su desarrollo no es satisfactorio.

Leucaena leucocephala was introduced into China in about the 1920s. At present, some old leucaena (common type) trees can still be seen in Guangdong, Fujian, Yunnan, and Taiwan provinces as well as in Guangxi Autonomous Region. The common type is a Hawaiian-type shrub. In August 1961, the Tropical Crops Cultivation Research Institute introduced from Central America some seeds of Salvador-type leucaena for test planting. The plant proved superior to the common leucaena in a 3-year trial so that, in 1965, the planting trials were extended to other areas where common leucaena has been found. The results indicated that Salvador-type leucaena is well adapted to China and can be planted from Xisha Islands (16°50'N), Guangdong Province, to Wuchang City (30°18'N), Hubei Province, but that the optimal growing area is the region south of the Tropic of Cancer. The best soil for it is considered to be the well-drained, deep, neutral (slightly alkaline or slightly acidic) sandy loam of above-average fertility.

Salvador is a fast grower, with good regeneration ability and prolonged productivity. It is a versatile legume that provides forage, green manure, firewood, and timber — a candidate for projects that integrate agriculture, forestry, and animal husbandry. It is a means to diversify farming and improve the ecosystem. The results of the early trials interested many departments involved with agriculture, forestry, and animal husbandry. The area under test planting is more than 2000 mu (about 133 ha) at present.

[1] The author was unable to attend the workshop because of illness but submitted this paper for inclusion in the publication.

Table 1. Comparison of growth characteristics of common and Salvador-type leucaena at 28 months.

	Common	Salvador
Height (m)	2.35	4.95
Diameter (cm)	2.5	4.8
Leaf-stalk (cm)	12.1	18.3
Pinnule length (cm)	9.2	9.9
Leaflet length (cm)	1.5	1.7
Leaflet width (cm)	0.4	0.5
Flower diameter (cm)	2.5	2.7
Pod length (cm)	15.8	23.5
Pod width (cm)	1.6	2.2
Seeds/pod	20.1	22.8
Seed length (cm)	0.7	0.9
Seed width (cm)	0.4	0.6

The trial plot with which I am involved is located at 19°30′N and 109°30′E on an experimental farm at an elevation of 149 m where a tropical monsoon climate prevails. The annual mean temperature here is about 23.5°C. The annual rainfall averages 1700 mm, 87.3% of which is in May–October — the concentration resulting in distinct wet and dry seasons. The sun shines about 2000 h a year. The soil is granite-derived, lateritic loam, with a pH of 5.3 and moderate fertility, containing 1.5% organic matter.

Results

Salvador-type leucaena is an evergreen, leguminous tree, whose stature, leaves, inflorescence, pods, and seeds are all larger than those of the common type (Table 1).

Adaptability

Growth in trial plantings at Xisha Islands, Hainan Island, Guangzhou City, Nanning City, and Wuchang City was satisfactory (Table 2). The leucaena showed good tolerance to cold, remaining nearly intact when the temperature at Guangzhou and Nanning dropped to −1°C. At −5.2°C in Wuchang City, the aboveground parts of the trees were damaged but rebudded in May the next year. The optimal temperature for its growth is 25–30°C; temperatures below 10°C halt growth. The trial plantings exhibited heat tolerance, but the root systems were scorched when the surface temperature reached above 50°C. Thus, the ideal growing area seems to be the region to the south of the Tropic of Cancer (23.5°N).

Salvador-type leucaena is a deep-rooted plant, with an aggressive taproot that can penetrate deep into the soil and thus enable the plant to withstand drought.

In 1965, it was planted on the coastal sandy soil in Dongfang County, west Hainan Island, and grew well. The climate in this area is dry and hot, with an annual precipitation of less than 1000 mm. A survey in 1981 indicated that the plants were 12 m high and 30 cm thick at 50 cm above ground.

The plants did well on most types of soil (Table 3); however, fertile, neutral to slightly alkaline, coastal mud flats suit them best, and the rich, slightly acid, sandy-clay paddy soil is also particularly suitable. The plants also thrive on deep acid, hilly lateritic loam, with moderate fertility but grow poorly on highly acid and barren red sandy soil and coastal sandy soil. On poor lateritic soil, with high pH (Xiaoliang of Dianbai County, Guangdong Province), the

Table 2. Observations on growth performance of Salvador-type leucaena in five locations.

	Xisha Islands	Danxian County, Hainan Island	Guangzhou City	Nanning City	Wuchang City
Tree age (months)	31	156	24	168	6
Height (m)	5.25	12.0	7.5	16.0	2.54
Diameter (cm)	4.9[a]	28.6[a]	10.0[a]	40.0[a]	5.1[b]
Flowering and pod formation	Good	Good	Good	Good	Pod frosted
Wintering	Damage free	Damage free	Slightly defoliated	Slightly defoliated	Top winter killed; resprouted in spring
Maximum monthly mean temperature (°C)	23.8	16.7	13.2	13.2	3.9
Absolute minimum temperature (°C)	15.3	6	0	1.7	-5.2

[a] Measured at breast height.
[b] Measured at 20 cm above ground.

Table 3. Influence of soil types on the growth of Salvador-type leucaena.

Soil type	Location	pH	Organic matter (%)	Tree		
				Height (m)	Diameter (cm)	Age (months)
Coral-derived	Yongxing Island, Xisha Islands	6.8	4.2	5.25	4.9	32
Coastal, light mud-flat loam	Baitenghu, Doumen County	7.3	3.0	3.26	2.2	8
Coastal sand	Brigade-run tree farm, Dianbai County	5.6	Trace	0.25	—	36
Granite-derived, red lateritic loam[a]	Xiaoliang, Dianbai County	4.6	0.9	3.38	3.6[b]	18
Granite-derived, red loam	SCATC	5.3	1.56	4.95	4.8[c]	28
Red sandy	Coconut Experimental Station, Wenchang County	4.6	0.51	0.15	—	12
Paddy	Changning, Boluo County	6.4	2.1	6.26	7.5	36

[a] Trenches, 50 cm deep, were dug and rubbish manure was applied at the rate of 20 - 25 kg/tree.
[b] Measured at the ground surface.
[c] Measured at breast height.

plant also grows satisfactorily when manure is applied in deep trenches at planting.

Germination and Growth

Treated seeds of Salvador-type leucaena germinate about 7 days after sowing in April. The seedlings are slow starters, whose root systems develop faster than the aboveground parts. Root nodules begin to form (not artificially inoculated) on some root systems as the third leaf emerges. At 3 months, the aboveground parts grow more quickly, and 5-month-old trees may measure 2.4 m high, with a diameter of 1.9 cm at 20 cm above ground. During hot and rainy seasons, the cut stump resprouts rapidly, a 40-day-old renewal shoot being up to 100 cm long. Some of the plants transplanted in spring and summer flower and pod in the same year, and the main florescence occurs between March and April or August and September. Pods ripen between May and June or October and November. A good, 14-year-old tree produces as much as 10 kg of seeds a year. The pod, when ripe, bursts, and the ejected seeds germinate and grow spontaneously.

Uses

The Salvador type gives rather high yields of tender shoots and leaves, which are highly nutritious as forage. From three cuttings in 1979, tender shoots and leaves were 1706 kg/mu and woody stems 534 kg/mu; respective figures from five cuttings in 1980 were 3826 kg/mu and 594 kg/mu. Analysis showed

Test plantings of leucaena at close spacing.

that the tender shoots and leaves contained 74.5% water, 6.24% crude protein, 1.12% crude fat, 5.18% crude fibre, 11.45% nitrogen-free extract, and 1.61% crude ash. An annual yield of fresh tender shoots and leaves of 3000 kg/mu is equivalent to 765 kg dry matter, of which 157 kg is crude protein. These yields are far superior to those obtained from other tropical forage crops.

As manure, leucaena also contains a high percentage of nutrients. Analysis indicated that, in the flowering phase, the fresh tender shoots and leaves contain 0.6% N, 0.084% P (P_2O_5), and 0.53% K (K_2O). Extrapolated to an annual yield (3000 kg/mu), the nutrients would constitute 18 kg N, 2.52 kg P, and 15.9 kg K, equivalent to 90 kg of ammonium sulfate, 14 kg calcium superphosphate, and 33 kg of potassium sulfate, respectively.

The tree grows fast and resprouts rapidly after being cut. In addition, it gives rather hard wood, with a short cutting cycle. Therefore, it is a suitable species for firewood forests. According to Xu Yanqian and Huo Yinqiang (1981), wood volume of a 6-year-old leucaena tree is 0.11397 m^3. At 334 trees/mu, the growing stock should be 38 m^3/mu, corresponding to an annual increment of more than 6.3 m^3/mu.

Leucaena Research in Taiwan

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Since 1975, 110 experimental plantations in lowland areas in Taiwan have been established for wood and forage production. Data on wood yield of different varieties, at different spacings, on different sites have been collected and are presented here. The effects of lime and phosphorus on the growth of leucaena have also been investigated, in both pot and field trials, as have the yields of forage from different varieties of leucaena. Wood and forage utilization and other miscellaneous research projects are also reviewed. Recommendations that would strengthen research on leucaena are proposed.

Depuis 1975, 110 plantations expérimentales ont été établies dans les basses terres de Taiwan en vue de la production de bois et de fourrage. On a pu recueillir une somme d'informations sur les rendements de différentes variétés d'après leur espacement en divers endroits, dont nous donnons ici un résumé. On a étudié également les effets de la chaux et du phosphore sur le développement de Leucaena *dans des essais en pots et en parcelles, ainsi que sur la production de fourrage de différentes variétés de cet arbre légumineux. L'utilisation du bois et du fourrage, et d'autres projets de recherche sont également passés en revue et l'on formule certaines recommandations qui pourraient stimuler la recherche sur* Leucaena.

Desde 1975, se han establecido en tierras bajas de Taiwan 110 plantaciones experimentales para producción de forraje y madera. Los datos recogidos sobre rendimiento de las diferentes variedades, a diferentes espaciamientos y en diferentes sitios, se presentan en este trabajo. También se han investigado los efectos de la cal y el fósforo sobre el crecimiento de la leucaena, tanto en vasijas como en el campo, así como los rendimientos del forraje de diferentes variedades de leucaena. También se reseñan en este trabajo la utilización de madera y forraje y otra variedad de proyectos de investigación. Se proponen recomendaciones que fortalecerían la investigación sobre leucaena.

Since the first accessions of *Leucaena leucocephala* in Taiwan in 1975, many varieties of the species have been introduced (Hu et al. 1977), and comprehensive research projects have been carried out by the National Science Council, the Council for Agricultural Planning and Development, the Taiwan Forest Bureau, the Taiwan Forestry Research Institute, the universities, and many wood-based industries, such as the Chung-Hwa Pulp Corporation and the Formosa Chemicals and Fibre Corporation (Kiang et al. 1980; Tai et al. 1980).

For wood and leaf-meal production studies, 110 experimental plantations were established in lowland areas of the island, and, although some of these have since been destroyed by rodents or cattle or been converted to other uses, there are still 64 plantations under study, representing a total 3.36×10^5 trees and 43.7 ha of land.

Besides the production studies, there are research projects on wood and leaf-meal utilization, the economic feasibility of planting leucaena for wood production, physiological and ecological characteristics of the crop, the toxic nature of mimosine, etc.

Since 1979, plantings have been conducted by the public and private organizations through loan and subsidy programs (Chiang 1980b,c; Huang and Tsai 1981).

Results of Research

Valuable data have been generated from the experimental plantations. The most important results deserve mention.

Yield trials of the Salvador-type leucaena, i.e., K8, K72, and S1, with a local variety for comparison purposes were conducted at six locations in Taiwan in 1976. The annual growth in volume of the introduced varieties was as much as 10 times that of the local variety and, at 3 years after planting, ranged from 37.24 m^3/ha at Tu-Lan to 0.39 m^3/ha at Shih-Tan (Table 1). Although the reasons for the huge discrepancy need further study, the findings indicated the necessity of careful site selection for economically feasible wood production from leucaena (Hu et al. 1980). Three of the sites in the study had average volume increments, at age 3 years, that were greater than 22 m^3 and, thus, reflect the characteristics

Table 1. Volume growth of trial plantations of leucaena at six locations (2500 trees/ha) in Taiwan.

Location	Elevation (m)	Variety[a]	Volume (m^3/ha) 1 year	2 years Total	2 years Annual	3 years Total	3 years Annual
Tu-Lan	100	S	3.6	52.6	26.3	117.7	37.2
		L	0.6	6.3	3.1	12.1	4.0
Ta-Ma-Li	10	S	2.0	39.5	19.7	67.5	22.5
		L	0.4	3.3	1.7	5.7	1.9
Kang-Kou	20	S	2.5	33.8	16.9	66.4	22.1
		L	0.4	3.1	1.6	5.7	1.9
Yun-Shuei	140	S	—	8.5	4.3	30.6	10.2
		L	—	0.6	0.3	2.0	0.7
Ta-Tan	20	S	—	1.3	0.7	2.4	0.8
		L	—	0.2	0.1	0.2	0.1
Shih-Tan	380	S	—	0.4	0.2	1.2	0.4
		L	—	—	—	0.2	0.1

[a] S = average of several varieties of Salvador-type leucaena. L = local variety used for comparison purposes.

of areas suitable for production. The Salvador varieties on the three sites at a spacing of 2500 trees/ha and on another site (Chia-Lin) at a spacing of 4400 trees/ha (Table 2) did not differ significantly in performance: these results imply that any one of them would be suitable

Table 2. Volume growth of different varieties of Salvador-type leucaena on four sites in Taiwan.

Location[a]	Variety[b]	Age (years)	Spacing (trees/ha)	Height (m)	DBH[c] (cm)	Annual volume (m^3/ha)
Tu-Lan	K8	3	2500	9.5	12.3	40.3
	K72	3	2500	10.0	11.9	38.1
	S1	3	2500	9.4	11.1	33.3
	L	3	2500	—	—	4.0
Ta-Ma-Li	K8	3	2500	10.2	9.2	22.7
	K72	3	2500	11.4	8.5	19.4
	S1	3	2500	10.9	9.6	25.3
	L	3	2500	—	—	1.9
Kang-Kou	K8	3	2500	8.2	9.5	23.0
	K72	3	2500	8.9	9.6	25.6
	S1	3	2500	8.9	7.9	17.7
	L	3	2500	—	—	1.9
Chia-Lin	K8	3	4444	8.0	6.7	28.8
	K28	3	4444	8.5	7.2	34.2
	K29	3	4444	9.0	7.5	38.1
	K67	3	4444	8.6	7.3	34.9
	K72	3	4444	9.2	7.7	40.4
	S1	3	4444	9.3	7.4	37.8
	L	3	4444	4.8	2.8	2.5
Chia-Lin	K8	4	4444	8.3	7.3	26.2
	K28	4	4444	8.9	7.7	30.8
	K29	4	4444	10.0	7.8	34.5
	K67	4	4444	9.3	7.7	31.1
	K72	4	4444	9.8	8.0	34.8
	S1	4	4444	10.0	7.9	34.8
	L	4	4444	5.3	3.3	3.0

[a] Plantations at Tu-Lan, Ta-Ma-Li, and Kang-Kou were established in 1976, and the plantation at Chia-Lin was established in 1978.

[b] All the K varieties were distributed by J.L. Brewbaker and S1 was introduced from Santa Cruz Porillo Station, El Salvador. L = local variety, included for comparison purposes.

[c] DBH = diameter, breast height.

Table 3. Volume growth of 2-year-old leucaena at different elevations in two locations.

	Ta-Ma-Li				Chia-Yi			
Elevation	Soil pH	Height (m)	DBH (cm)	Annual volume (m^3/ha)	Soil pH	Height (m)	DBH (cm)	Annual volume (m^3/ha)
100	7.6	6.4	3.7	22.0	7.6	6.4	4.2	27.0
200	—[a]	—	—	—	4.5	3.4	1.4	1.5
400	6.2	5.7	3.9	21.0	4.5	1.5	1.3	0.5
600	6.2	5.3	3.8	18.5	—[b]	—	—	—

[a] Plantation damaged by landslide.
[b] Plantation damaged by grazing animals.

for a large-scale commercial planting program. The poor performance of the local variety in these trials indicates that appropriate measures are needed to prevent the possible contamination of the Salvador varieties by pollen of the local variety.

More importantly, the results indicate that the maximum annual production that could be expected from such plantations would be only about 40 m^3/ha at the age of 3 - 4 years. This amount is much lower than that reported for other tropical countries, such as the Philippines, Indonesia, and Hawaii (Van Den Beldt et al. 1982). Annual temperature, which is only 23 C in the warmest area in Taiwan (Hu and Kiang 1982), is probably the main reason for the differences, although other environmental factors, such as soil pH, annual rainfall, and photoperiod are also factors.

Jen (1980) studied the economic feasibility of planting leucaena for wood production in Taiwan and concluded that leucaena cultivation on slopes would be economically feasible only if annual wood production were higher than 40 m^3/ha.

Experimental plantations were established at four elevations, i.e., 100, 200, 400, and 600 m above sea level, in each of two locations in Taiwan. The spacing for planting was 1 m × 1 m (10 000 trees/ha). The annual growth, after 2 years, of the plantations at Ta-Ma-Li in eastern Taiwan ranged from 18.5 m^3/ha to 22 m^3 (Table 3) and was not statistically different at any of the sites. In contrast, Chia-Yi plantation in western Taiwan registered the highest volume growth (27 m^3/ha) at the elevation of 100 m, but, at higher elevations, growth was less than 2 m^3, which is negligible for wood production. The huge differences probably reflect soil pH rather than elevation, with wood production appearing to be feasible as high as 600 m above sea level if soil quality is good (Hu et al., in press).

In studies of the effects of different spacings on volume growth, several trial plantations were established at different locations in 1978 and 1979. Five spacings, 2 m × 2 m, 2 m × 1 m, 1 m × 1 m, 1 m × 0.5 m, and 0.8 m × 0.3 m, were used, equivalent to 2500, 5000, 10 000, 20 000, and 40 000 trees/ha. The plots ranged from 500 m^2 to 1000 m^2, and only the trees planted in the central 10 m × 10 m of each plot were measured for data collection (Table 4).

At age 2 - 4 years, the trees planted at high densities did not have any advantage, in volume growth, over trees at densities of 5000 and 10 000 trees/ha. Moreover, because the percentage of trees with diameters smaller than 3 cm was much higher in densely treed plots than in low-density plots, the economic value of the wood produced in the former was much lower.

The effects of applications of lime and phosphorus on the growth and nutrient levels of leucaena have also been studied. Both pot and field trials were conducted (Hu and Cheng 1980a,b). The pot tests were initiated on 22 February 1979 with the application of lime to adjust the pH of the acidic soil from 4.8 to 6.0, 7.0, and 8.0. The tests were completed in September 1979. The results indicated that height growth and dry-matter production of seedlings were closely correlated with soil pH (0.933 and 0.940 respectively). Height growth (35 cm in the control, 84 cm at pH 7) and dry matter (28 g/pot in the control, 126 g/pot at pH 7) increased with increasing soil pH up to 7 and decreased thereafter. The optimum soil pH ranged from 6.0 to 7.0. The uptake of nutrients also increased with increasing pH to 7.0 and decreased at higher pH levels. Applying lime to the soil (to pH 7) increased the availability of calcium, potassium, and phosphorus to the leucaena and reduced the availability of manganese and aluminum (Ta-

Table 4. Growth of leucaena planted at five spacings at Chia-Lin, Chih-Shang, Yu-Li, and Tou-Liu (Hu et al. 1980, 1982).

Location	Spacing[a] (trees/ha)	Annual volume growth (m^3/ha)[b] 1 year	2 years	2.5 years	3 years	3.5 years	4 years
Chia-Lin	2500 (2500)	7.0	30.7		33.8		24.9
	5000 (5000)	14.3	42.2	—	44.4	—	41.0
	10000 (9100)	21.4	38.1	—	41.9	—	34.8
	20000 (17100)	29.5	42.2	—	42.4	—	35.1
	40000 (28400)	28.8	37.9	—	37.7	—	33.4
Chih-Shang	2500 (4800)	1.4	8.4	—	17.8	—	—
	5000 (5800)	4.9	13.4	—	21.5	—	—
	10000 (10000)	4.0	14.5	—	19.0	—	—
	20000 (22200)	7.2	15.6	—	26.8	—	—
	40000 (34600)	9.6	18.6	—	20.7	—	—
Yu-Li	2500 (2525)	—	—	9.1	—	6.6	—
	5000 (4875)	—	—	11.8	—	9.0	—
	10000 (9800)	—	—	18.0	—	13.2	—
	20000 (16550)	—	—	18.5	—	16.9	—
	40000 (37350)	—	—	25.5	—	21.9	—
Tou-Liu	2500 (3000)	2.6	13.3	—	18.6	—	—
	5000 (4700)	3.3	17.0	—	20.1	—	—
	10000 (9200)	3.9	18.4	—	21.7	—	—
	20000 (16800)	3.4	18.2	—	22.7	—	—
	40000 (31600)	11.6	25.4	—	25.5	—	—

[a] Figures in parentheses show the actual number of stems/ha when last measurement was taken.

[b] Volume of individual trees was calculated as $0.5 \cdot (DBH)^2 \cdot h$ where DBH is the diameter, breast height, and h is height. The volume of the plantation was extrapolated from the individual volume on the basis of the number of trees actually in the stand.

Table 5. Extractability of soil nutrients at four pH levels [a]

pH	Organic matter (%)	Total N (%)	Extractable base (meq/100 g soil) Ca	K	Al	Extractable Mn (ppm)	Available P (ppm)
4.82	2.62	0.126	1.213	0.683	4.670	21.4	0.13
6.00	2.70	0.129	3.841	0.750	2.120	11.0	0.20
7.00	2.70	0.122	5.391	0.755	1.392	8.7	0.13
8.00	2.58	0.125	7.328	0.691	1.268	7.6	0.09

[a] The variance ratio, F, was not significant for the differences in organic matter and total nitrogen, but the differences were highly significant ($P < 0.01$) for calcium (69.79), potassium (4.19), and aluminum (131.84) and were significant ($P < 0.05$) for manganese (3.37).

ble 5). The field trials were conducted in the nursery near Taipei. Original pH of the soil was 4.7, which was adjusted to about 6.0, 7.0, and 8.0 by the addition of $CaCO_3$ — 4000, 9500, and 14 950 kg/ha respectively; phosphorus (0, 100, and 200 kg/ha) was also applied (Hu and Cheng 1981; Hu et al. 1981). The results (Table 6) after 16 months indicated some important aspects of the response of leucaena to lime and phosphorus on acidic soils. The pH levels of the soil, again, were positively correlated with height, diameter, and dry-matter production, the multiple correlation coefficients being 0.867, 0.914, and 0.776, respectively. As in the pot trials, the growth of the leucaena increased with increasing soil pH up to 7. Chemical analyses of the tops of the trees showed that the nutrient uptake increased with increasing soil pH. Nutrient availability of the soil was also analyzed, and the analysis suggested that the beneficial effect of liming is at least partly from its reduction of the availability of aluminum and manganese in the soil. Aluminum toxicity in acidic soils is a limiter not only of plant growth but also of rhizobial growth.

Table 6. Growth of leucaena after 16 months as affected by liming.

pH	Lime added (kg/ha)	Height (cm)	Diameter (cm)	Dry weight of tops (kg/ha)	Dry weight of roots (kg/ha)
4.7	0	92.9	1.07	3221	1806
6.0	4000	267.3	3.13	7716	3082
7.0	9500	303.0	3.38	10886	3793
8.0	14950	335.8	3.55	15462	5879

Table 7. Soil pH value at time of lime application (original) and 16 months later.

Original pH	pH value in soil depth of 0–5 cm Range	0–5 cm Mean	5–20 cm Range	5–20 cm Mean
4.7	4.28–4.78	4.54	4.29–5.00	4.72
6.0	5.18–7.24	5.91	4.98–5.66	5.26
7.0	6.09–7.35	6.88	5.07–5.61	5.37
8.0	6.50–8.33	7.41	5.37–7.87	6.50

Nitrogen content of all the soils in the study had increased at 16 months after planting. This increase was about 17% in the soils at pH 6.0.

At 16 months after planting, the soil pH value had decreased but was still higher than that of the control (Table 7). Thus, the effects of liming can be maintained for at least 16 months.

Although these field trials gave some indication of what leucaena contributed to the soil, they did not document what the crop was taking from the soil. This was the focus of a recent study that measured the nutrient accumulation of the aboveground portion of the plant. Wood and foliage samples were collected from Chia-Lin 3 years after establishment of the plantation. These were analyzed and reported by Cheng et al. (in press). The nutrients measured were N, P, K, Ca, and Mg. The results indicated no significant differences in the amounts (kg/ha) of nutrients being taken by the trees at densities of 2800, 5100, 9700, 17 300, and 32 100 trees/ha except for magnesium, which was being accumulated by the trees significantly more at a density of 5100 trees/ha than at any other density. Total accumulation of nutrients, on a per-hectare basis, for N was from 222 to 441 kg; for P was 11–27 kg; for K, 174–331 kg; for Ca, 138–305 kg; and for Mg, 31–62 kg. This result is useful as a rough estimate of the depletion of the nutrients from the forestland — a factor that tends to be forgotten or ignored by producers.

Yields (t/ha) of forage from different varieties of leucaena have also been studied. An experimental plantation for this purpose was established in southern Taiwan and included seven varieties of the Salvador type, two varieties of the Peru type, and a local variety for comparison purposes. The spacing was 0.2 m × 0.5 m, equivalent to 100 000 plants/ha. Plants were cut at 20 cm above ground when they were about 150 cm high. The results (Shih and Hu 1981, 1982) after eight cuttings over 2 years indicated no significant differences in the yields of green forage from the introduced varieties, the ranges for the 1st and 2nd years being, respectively, 62.3–87.0 t/ha and 71.0–117.6 t/ha. However, all the introduced varieties yielded significantly ($P < 0.05$) more than the local variety.

Recently, the properties of wood from leucaena in Taiwan were studied by Tang (1981) and Tang and Ma (1982), and the feasibility of producing pressed, laminated wood from leucaena to make furniture was investigated by Jai et al. (1982). Many experiments had earlier been conducted, by both government and private organizations on the use of leucaena for pulp and paper making. All the published studies to date indicate that the wood is promising for the production of pulp, paper, and artificial fibre (Ku et al. 1981). One study showed that leucaena fibres have potential as animal feed (Ku and Lin 1982). Tai et al. (1982) recommended that the research on wood utilization be strengthened.

Some insects and diseases affecting leucaena in Taiwan have been studied and reported (Chang 1980; Chang et al. 1982; Hsieh 1980, 1982). In addition, physiological and ecological studies of leucaena plants have been conducted by Chen and Chen (1981), and Chou (1982), and Kuo et al. (1982) reported the allelopathic potential of leucaena. Studies on *Rhizobium* selection and inoculation are just in the early stages within the country, but some work has been reported by Young and Chao (1982).

Extension

The information produced and techniques developed by research workers have been communicated to both the forest managers and the tree farmers (Hu 1976, 1979, 1980; Chiang 1980a; Kiang 1981; Tai et al. 1982; Wang et al. 1982), and the two largest private timber-processing companies in the country, Chung-Hwa Pulp Corporation and Formosa Chemicals and Fibre Corporation, are encouraging extensive plantations of giant leucaena to ensure continuity in the raw-material supply. Each company has its own system for extension, although both offer contracts for the establishment of the plantation. In addition, one company subsidizes the work, and the other offers interest-free loans to the landowners. As most of the plantations are less than 2 years old, it is still too early to judge the effectiveness of the approaches.

Future Research

The experiences and results of research to date indicate that future efforts should be devoted to:

- Determining site requirements of leucaena;
- Examining, on a long-term basis, the effects of liming on the growth of leucaena in acid soils;
- Investigating the nutrient cycling within leucaena plantations that are short rotation;
- Developing labour-saving silvicultural practices, including the use of herbicides, fertilizers, irrigation, and machinery;
- Introducing other varieties of leucaena to broaden the genetic base;
- Introducing other fast-growing, leguminous-tree species with different site requirements so that the range of choice of planting site becomes broader; and
- Establishing seed orchards to produce superior seeds for planting.

Research on Leucaena and Other Nitrogen-Fixing Trees at the Thailand Institute of Scientific and Technological Research (TISTR)

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Since 1977, TISTR has been conducting observation trials on leucaena, and in 1979 trials were also set up at Senanikom. These were initially planned for seed multiplication, for study of the growth characteristics, and for evaluation of the crop's potential use as fuelwood, raw material for charcoal, pulp, and paper as well as for construction purposes. Seedlings were raised and planted at a spacing of 1 m × 1 m (TISTR) and 1 m × 0.5 m (Senanikom). The soil was fertilized with NPK (6/18/24 kg/rai — 6.25 rai = 1 ha) at 6 and 12 months after planting. After 4.5 and 3.5 years, respectively, the plants were measured for their height and diameter at breast height (DBH). Average plant height at TISTR (4.5 years) was 12 m with DBH 13.4 cm and at Senanikom (3.5 years) 9.4 m with a DBH of 6.5 cm.

Depuis 1977, l'Institut de recherches scientifiques et technologiques de Thailande (TISTR) poursuit des observations concernant Leucaena *et, en 1979, des essais ont également été entrepris a Senanikom. Ces derniers devaient d'abord porter sur la multiplication par semis, sur les caractéristiques de développement et sur la valeur de la récolte comme sources possibles de bois de chauffage, de charbon de bois, de pâte et de papier et comme matériau de construction. Les semis obtenus ont été mis en terre à l'écartement de 1 m × 1 m (TISTR) et de 1 m × 0,5 m (Senanikom). Ils ont reçu une fumure complète de NPK (6/18/24 kg/rai — 6,25 rais = 1 ha) à 6 et 12 mois après la plantation. Après 3,5 et 4,5 ans, respectivement, on a mesuré la hauteur des plants et leur diamètre à hauteur d'homme (DBH). Au TISTR (4,5 ans) les plants étaient hauts de 12 m, avec un DBH de 13,4 cm, et à Senanikom (3,5 ans) les résultats étaient respectivement de 9,4 m et 6,5 cm.*

Desde 1977, el Instituto Tailandés de Investigación Científica y Tecnológica (TISTR) ha estado realizando pruebas de observación sobre leucaena, y en 1979 se establecieron pruebas también en Senanikom. Estas pruebas se programaron inicialmente para multiplicación de semillas, para estudio de las características de crecimiento y para evaluación del uso potencial del cultivo como combustible, materia prima para carbón, pulpa y papel, así como para efectos de construcción. Las plántulas se sembraron con un espaciamiento de 1 m × 1 m (TISTR) y 1 m × 0,5 m (Senanikom). El suelo fué abonado con NPK (6/18/24 kg/rai —6,25 rai = 1 ha) a los 6 y 12 meses después de la siembra. Después de 4,5 y 3,5 años, respectivamente, se midieron la altura y diámetro de las plantas a la altura de pecho (DBH). La altura promedio en TISTR (4,5 años) fué 12 m con DBH 13,4 cm y en Senanikom (3,5 años) de 9,4 m con DBH de 6,5 cm.

A few decades ago, more than 50% of Thailand was covered with forests, but, today, forests cover only about 25% of the whole country. Landsat imagery shows the annual depletion of the forestland to be about 10% (Klankamsorn and Charupatana 1981), and most of the timber felled is used for fuel. Thailand uses some 400 t of charcoal every day, extracted from the forest. This deforestation has prompted interest in fast-growing, nitrogen-fixing trees that have been ignored (Chomchalow 1980; Korvanich 1982) in the past.TISTR research has mainly focused on leucaena, but other species are now being investigated in a project supported by the US National Academy of Sciences. Since the mid-1970s, TISTR has conducted varietal, spacing, and utilization trials on leucaena, and the results of some of the work are presented in this paper.

Thanks to international research cooperation around the world, several varieties and species of fast-growing, nitrogen-fixing trees have been either selected or chosen for biomass production (NAS 1977, 1979, 1980; Brewbaker and Hu 1981).

TISTR Research

Research on nitrogen-fixing trees being conducted at the Institute is divided into two categories, namely research on *Leucaena leucocephala*, which has been under way since 1977, and research on other species.

Seeds of leucaena were introduced to the Institute from the University of Hawaii by Narong Chomchalow. Since then, field trials have been established on the central plain near Bangkok; the southern, sandy coast; Chumphon Province; and the northern subtropical areas of Chiang Mai Province.

Table 1. Physical properties of leucaena pulp by NSSC (neutral sodium sulfate chemimechanical) process.[a]

	Age of leucaena used in unbleached NSSC pulp (months)				
	41	36	29	18	10
Unbleached yield (%)	66.05	66.56	63.56	65.46	65.71
Beating time (min)	13	13	12	12	13
Basis weight (g/m^2)	55.49	59.80	59.19	60.73	61.04
Breaking length (m)	7083	7227	6429	5987	6004
Burst factor	46.64	48.59	44.04	41.29	46.41
Elmendorf tear factor	77.1	81.9	81.1	82.2	76.8
Folding endurance	127	131	123	97	256
Brightness (%)	27.0	27.0	27.0	27.0	30.0
Opacity (%)	96.5	97.0	97.0	96.5	94.5

[a] NSSC pulping is with Na_2SO_3 (15%), Na_2CO_3 (3.5%), at a maximum temperature of 170 C. The time taken to reach maximum temperature is 1 h, and the time at maximum temperature is 4 h.

The first experimental trials were planned for seed multiplication, for study of the growth characteristics of leucaena, and for evaluation of the crop's potential use as fuelwood as well as raw material for charcoal, pulp, paper, and construction. Seedlings were raised and transplanted at spacings of 1 m × 1 m at TISTR and 1 m × 0.5 m at Senanikom. Before leucaena, wing beans (three crops) had been cultivated on the sites. The soil was fertilized with NPK at 6/18/24 kg/rai (6.25 rai = 1 ha) 6 and 12 months after planting.

The trees were randomly cut between ages 1 and 3.5 years for tests of their physical properties. Moisture content was shown to be 70%. At 3.5 years, the leucaena exhibited a hardness of 1475 kg compared with 731 kg for eucalyptus and 540 kg for rubber wood at the same age. The height and diameter at breast height (DBH) of trees at TISTR after 4.5 years' growth were 12 m and 13.4 cm, respectively, whereas the corresponding figures for 3.5-year-old trees at Senanikom were 9.4 m and 6.5 cm.

Heating value of leucaena charcoal (28 265 kJ/kg) also compared favourably with that of eucalyptus (26 095 kJ/kg) and rubber wood (32 738 kJ/kg).

Pulp from leucaena in two pulping processes — NSSC and sulfate — (Tables 1 and 2) was deemed medium to high grade when compared with other hardwood pulps. The NSSC process is suitable for converting leucaena into unbleached-grade pulp but not bleached pulp. However, the sulfate pulping method produced suitable pulp for both bleached and unbleached grades. Pulp from the older trees was better quality than that from the young ones.

Table 2. Physical properties of leucaena pulp by sulfate process.[a]

	Age of leucaena used in bleached sulfate pulp (months)				
	41	36	29	18	10
Yield (%)					
Unbleached (screened)	55.77	45.19	43.58	43.77	43.24
Bleached	46.54	39.08	40.91	42.80	42.41
Beating time (min)	12	10	14	15	13
Basis weight (g/m^2)	61.09	62.88	62.65	57.71	64.51
Breaking length (m)	5406	4056	3670	3408	3392
Burst factor	50.59	19.88	17.46	20.10	14.69
Elmendorf tear factor	105.2	32.6	49.9	53.7	56.7
Folding endurance	74	23	7	8	5
Brightness (%)	70.0	70.0	70.5	74.0	74.0
Opacity (%)	99.5	80.5	84.0	83.5	84.5
% Cl_2 in bleaching	12.6	8.1	7.0	7.8	6.4

[a] Sulfate pulping is with Na_2O (12%), at 25% sulfidity. Maximum temperature is 170 C. The time taken to reach maximum temperature is 1 h, and the time at maximum temperature is 2 h. Bleaching is in three stages.

Besides these laboratory tests, wood from leucaena was cut into fillets for parquet making. At present, a house is being built at Chumphon Province by TISTR using leucaena for the parquet flooring.

Since 1979, field trials have also been under way on the coastal, sandy soil of Chumphon Province about 400 km south of Bangkok. To date, about 10 ha have been planted with leucaena. The soil has a pH 4.3, 1.01% organic matter, 10 ppm phosphorus, 22 ppm potassium, and 0.087% total nitrogen. Because the soil is poor, organic matter as well as fertilizer and liming are required at the initial stages of growth. At 3 years, the average height of leucaena is 8.4 m, with an average DBH, 15.9 cm. Seedlings were raised in plastic bags for transplanting, and it was found that seedlings kept in bags more than 2 months had bent roots that caused poor establishment. When these seedlings were transplanted, the roots spread horizontally instead of penetrating the subsoil. However, seedlings younger than 2 months established well. Seedlings raised in plastic dibbling tubes had poorer establishment than those in the plastic bags probably because the tubes contain less soil.

In Mae Jo District of Chiang Mai Province, about 750 km from Bangkok, a study of the yield and growth characteristics of leucaena at various spacings was launched. A complete, randomized block design was employed in a plot 26 m × 14 m. Leucaena was planted at four spacings, 2 m × 0.25 m, 2 m × 0.5 m, 2 m × 1 m, and 2 m × 2 m. The soil was characterized by low humic gray with medium base saturation, low phosphate and potassium content, medium–high content of organic matter, and a pH 5.6.

Chemical fertilizer (NPK, 5 : 10 : 10) was applied at the annual rate of 100 kg/rai in two applications: in the plant hole before planting and 3 months after planting. Subsequently, fertilizer was applied once a year in bands.

The results (Table 3) indicated that wood weight and volume were negatively correlated with spacing at 1.5 years, but, at 3 years, 50-cm spacing between hills gave the maximum yields. The 1.5-year-old leucaena had a dry-wood combustion value of 4770 kcal/kg and a density of 0.7 (medium hardwood).

Other Nitrogen-Fixing Trees

In 1982, TISTR began field trials and testing of selected species of other fast-growing, nitrogen-fixing trees. The sites are in the sandy soil at the southern coast of Chumphon Province and in Chan Thuek, Nakhon Ratchasima Province, about 200 km northeast of Bangkok. The experiments aim to screen a wide range of species for their ability to grow under local conditions. In-depth investigations of the plant–*Rhizobium* interaction, the requirements for phosphate fertilizer, and tree density are also planned, as are the establishment of seed orchards and testing of the trees for utilization as firewood and in industrial applications.

There are four plots in each of the two sites,[1] including variety, spacing, and fertilizer trials. In the variety trials, 18 species[2] are being

[1] Chumphon: coastal sandy soil, with 1.01% organic matter, 10 ppm P, 22 ppm K, 0.087% total N, and pH 4.3. Chan Thuek: sandy loam soil, with 1.32% organic matter; 9 ppm P; 108 ppm K; 0.114% total N; and pH 4.7.

[2] The species are *Acacia auriculiformis, A. mangium, Albizia falcataria, A. lebbek, A. procera, A. lebbekoides, Calliandra calothyrsus, Cassia siamea, Casuarina equisetifolia, C. junghumiana, Eucalyptus camaldulensis, Gliricidia sepium, L. leucocephala* (K8), *L. diversifolia, Enterolobium cyclocarpum, Pithecellobium dulce, Samanea saman,* and *Sesbania grandiflora*.

Table 3. Yield and growth of leucaena at Chiang Mai Province at various spacings.

Age (years)	Spacing (m × m)	Plant height (m)	Trunk (dry weight t/ha)	Total biomass (dry weight t/ha)	Trunk volume (m^3/ha)	Total volume (m^3/ha)
1.5	2 × 0.25	5.6	17.1	19.7	23.5	26.8
	2 × 0.5	6.4	14.1	17.2	19.3	23.5
	2 × 1	6.6	10.9	16.6	14.7	22.6
	2 × 2	6.5	7.1	13.3	9.6	18.0
3	2 × 0.25	6.6	19.4	22.1	26.4	30.2
	2 × 0.5	7.7	24.7	27.7	33.9	37.7
	2 × 1	7.4	17.9	20.5	24.7	28.1
	2 × 2	7.3	18.6	21.9	25.5	29.7

compared. The augmented design, with six replications, is being employed. Plot size is 6 m × 10 m, with 1 m × 1 m spacing. Data will be collected every 6 months, trees being cut from two of the six replications. The entire crop will be cut after 3 years. The trees are now 2 months old, and *Eucalyptus camaldulensis*, *Sesbania grandiflora*, *L. diversifolia*, and *L. leucocephala* are the fastest growing so far. In the spacing trials, a split-plot design with two replications is being used. Ten species are the main plots and the spacings of 1 m × 0.5 m, 1 m × 1 m, 1 m × 1.5 m, 1 m × 2 m, 1 m × 3 m, and 1 m × 4 m are the subplots. The plot size is eight rows 10 m long at Chumphon and seven rows 12 m long at Chan Thuek. Data will be collected every 6 months, and all the trees will be cut for detailed measurements after 3 years.

In the fertilizer trials, the split-plot design with four replications is being employed. Ten species are the main plots, and four levels of phosphate application (3, 6, 12, 24 kg P_2O_5/rai) are the subplots. Plot size is 4 m × 10 m at Chumphon and 6 m × 10 m at Chan Thuek. Data will be collected every 6 months for 2 years when it is expected that this trial will be converted to some other experimental purpose. For the purposes of seed multiplication and germ-plasm collection, a fourth plot has been established. About 18 accessions are represented.

Research on Nitrogen-Fixing Trees in Pakistan

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Pakistan is facing a wood crisis, and, at present, the area under productive forests in the country is 1.3 × 10^6 ha — an amount that is unlikely to increase. Any increases in production will come from greater yields per unit area made possible by activities such as planting fast-growing trees — poplars, eucalypts, and leucaena. Recognizing this, researchers in the country have turned their attention to such plants. For leucaena, they have conducted variety trials, investigated spacing and establishment regimens, etc. Studies conducted to date indicate that soaking leucaena seeds for 24 h does not significantly affect germination percent or time; that seedlings grown in polyethylene tubes 17 cm × 4.5 cm establish better than those in 17 cm × 2.5 cm tubes; that the optimal climate for K8 differs from that for K67, the former performing better at 25°23'N than at 34°01'N and the latter exhibiting the reverse trends. Other findings are also reviewed.

Au Pakistan, il existe une pénurie de bois. Actuellement la superficie constituée par des forêts exploitables est de 1,3 × 10^6 ha pour tout le pays et n'a guère de chance d'augmenter. Toute amélioration de la production devra provenir d'un accroissement du rendement par unité de superficie que l'on pourrait obtenir, notamment, de la plantation d'espèces à croissance rapide telles que peupliers, eucalyptus et Leucaena. C'est pourquoi, les scientifiques de ce pays portent beaucoup d'intérêt à ces végétaux. En ce qui concerne Leucaena, *ils ont effectué des essais de variétés, recherché les espacements et les régimes d'implantation les plus propices, etc. À ce jour, les recherches indiquent que le trempage des semences de* Leucaena *durant 24 h ne modifie guère les facultés germinatives en termes de temps ; que les semis cultivés en tubes de polyéthylène de 17 cm × 4,5 cm se sont mieux établis que ceux en tubes de 17 cm × 2,5 cm ; que le climat optimal pour le K8 n'est pas le même que pour le K67, le premier réussissant mieux à 25°23'N qu'à 34°01'N, alors que la tendance s'inverse pour le deuxième. D'autres constatations sont également exposées.*

Paquistán enfrenta una crisis de madera y, actualmente, el área bajo bosques productivos en el país es de 1,3 × 10^6 ha, una cantidad que difícilmente aumentará. Cualquier aumento en la producción tendrá que provenir de mayores rendimientos por unidad de área, posibles mediante actividades como la siembra de árboles de rápido crecimiento —álamos, eucaliptos y leucaena. Con esto en mente, los investigadores del país han tornado su atención hacia tales plantas. En cuanto a la leucaena, ellos han realizado una variedad de pruebas e investigado el espaciamiento y regímenes de establecimiento, etc. Los estudios indican actualmente que el remojo de la semilla de leucaena por 24 horas no afecta significativamente el porcentaje o el tiempo de germinación, que las plántulas que crecen en tubos de polietileno de 17 cm × 4,5 cm se dan mejor que aquellas en tubos de 17 cm × 2,5 cm, que el clima óptimo para el K8 difiere de aquel para el K67, el primero desempeñándose mejor a 25°23'N que a 34°01'N, y el último exhibiendo tendencias contrarias. Se reseñan además otros hallazgos.

Pakistan is a unique combination of deserts, alluvial plains, hills, and some of the highest mountains in the world. The diversity in climate and soil is reflected in the flora. The total forest area under the control of forest departments is 10.4 × 10^6 ha. Productive forest is 1.3 × 10^6 ha, the source of 1.5 × 10^6 m^3 fuelwood and 4.0 × 10^5 m^3 timber.

A large part of Pakistan is mountainous. On these areas subsist enormous human and cattle populations that, through unrestricted deforestation and grazing, have denuded the watersheds and have accelerated soil erosion. In the plains, also, the desert vegetation is being gradually removed for fuel and fodder. Heavy browsing, especially by goats and camels, is responsible for total devastation of the vegetation, and the deserts are rapidly expanding.

The human population is expected to rise from 82.75 million in 1980 to 111.21 million by 1990 — an increase that will boost the current requirement of fuelwood (16.6 × 10^6 m^3) by another 11.4 × 10^6 m^3. Timber needs are also increasing, but food requirements demand that agriculture be given precedence over forestry. It does not seem to be possible to earmark more state land for afforestation in the foreseeable future, but one way to bridge the gap between demand and supply of forest products is to increase the yield per unit area by planting fast-growing tree species, such as poplars and eucalypts. These trees, especially poplars, are being planted on a large scale by farmers because they have become economically very attractive, with one tree after 5 years

fetching about US$ 12.0. *Acacia arabica* is another favourite of the farmers in the province of Sind. It is planted to reclaim the salt-saturated land.

During the last 5 years, leucaena has gained recognition, and Pakistan obtained small quantities of seed from different sources. Now, the seed is being collected from established plantations and is being distributed to forest departments.

Dalbergia sissoo and *A. arabica* are the two major species planted by foresters in the irrigated plantations and the riverine forests for fuel and timber in Pakistan.

Dalbergia sissoo is a large deciduous tree, 20–30 m high. The species is the major source of wood for the furniture industry in the country, and its plantations are raised initially from root–shoot cuttings and subsequently managed from root suckers and coppices. Plantations are thinned for fuelwood at the ages of 5, 10, and 15 years. Clear felling is done after 20 years, with 15–20 trees left standing for another 20–40 years. Average diameters at the ages of 5, 10, 15, and 20 years are 11.4, 19.3, 27.2, and 33.8 cm, and yields are 52, 115, 172, 223 m^3/ha, respectively.

Acacia arabica (A. nilotica) is a multipurpose tree of great economic importance. Average diameters at 5, 10, 15, and 20 years are 8.6, 19.3, 28.7, and 37.1 cm, and total volume is 82, 144, 184, and 205 m^3/ha.

The other two leguminous species planted on a small scale are *Albizia lebbek* and *A. procera*, with the latter gradually becoming more important. Plantations of these two species are watered from mid-April to mid-October every year, and they occupy the best agricultural lands in the country. The inputs cannot be justified in terms of output, and these species probably should be abandoned for faster-growing alternatives.

Sesbania aegyptiaca is another tree being planted by the farmers to improve the soil and to provide a windbreak as protection for banana, mango, and cotton crops in Sind. The tree attains an average height of 6 m and diameter of 15 cm after 5 years under irrigated conditions. The wood is used mainly for thatch, poles, posts, and cots.

Studies

Studies on *Leucaena leucocephala* have investigated seed scarification, seedling-container size, rate of growth, planting in low-rainfall zones, planting on eroded lands, etc.

Studies on scarification indicated that soaking the seed in water for 24 h prompted rapid germination in only about 5–10% of the seed, the rest taking much longer, even up to 50 days. To study the effects of different treatments researchers collected seeds from 1-year-old plants and divided them into six lots of 200 each. Four lots were soaked in water, for 24, 48, 72, and 96 h, respectively; one was soaked in cowdung for 96 h, and the other kept as control. All the lots were sown (24 July 1980) in polyethylene tubes and hand watered daily till germination was completed (13 September 1980). Germination started the day after planting in all cases (Table 1). The findings indicated that none of the treatments shortened the time of germination.

In studies of growth rates of leucaena in two different-sized containers, seed was sown in polyethylene tubes (17 cm × 2.5 cm and

Table 1. Effects of five scarification treatments on leucaena seed planted 24 July 1980.[a]

	Replication											
	1			2			3			4		
Treatment	A	B	C	A	B	C	A	B	C	A	B	C
Soaked in water												
24 h	3	7	15	4	8	16	5	9	18	7	12	21
48 h	2	3	9	3	5	11	2	4	10	4	6	13
72 h	4	9	15	4	8	14	3	7	13	4	8	18
96 h	2	3	9	2	4	11	3	6	14	2	4	10
Soaked in cowdung 96 h	3	7	12	2	5	12	4	6	14	3	8	12
Control	4	15	20	6	12	22	7	18	23	7	11	22

[a] A = germination started (25 July 1980), B = seedlings emerged by 15 August 1980, C = seedlings emerged by end of germination (13 September 1980).

Table 2. Estimated yields from leucaena compared with those from four other species.[a]

Species	DBH (cm)	Volume/tree (m^3)	Volume/ha (m^3)	MAI (m^3)
L. leucocephala	10	0.0464	116.00	29.00
E. grandis	12	0.0521	130.25	32.56
E. tereticornis	11	0.0580	145.00	36.25
A. arabica	11	0.0357	89.25	22.31
D. sissoo	12	0.0697	174.15	14.51

[a] DBH = diameter, breast height. MAI = mean annual increment.

Table 3. Survival, height, and diameter of six varieties of *L. leucocephala* after 2 years at Peshawar, Pakistan.

Variety	Survival (%)	Height (m)	Diameter (cm)
K8 (Mexico)	99	4.4	3.3
K28 (Salvador)	100	4.1	3.0
K29 (Honduras)	100	5.0	4.0
K67 (Mexico)	89	5.5	4.0
K132 (Mexico)	59	1.9	1.0
Local (Philippines)	79	4.7	3.5

17 cm × 4.5 cm) on 2 September 1979. Measurements of the seedlings were recorded on 20 May 1980, and, for the small and larger containers, respectively, the average lengths of shoot (cm) were 6.0 and 9.0; root lengths (cm), curled, 19.0, 18.0; diameters (cm) at the collar 0.14, 0.2, numbers of leaves 4.0, 18.0; and lengths of the pinna (cm) 2.0, 2.0, the plants in the larger diameter tubes showing considerably better progress. A further finding was that plants kept in the nursery for more than 8–9 months tended to become whippy, suffer from unbalanced root–shoot ratio, and have poor survival in the field.

Also, three test plantations of *L. leucocephala* were established with seed received from the Philippines, and all three were regularly irrigated for about 10 months of the year. The first plantation was in Peshawar in 1978 at 2 m × 2 m spacing. The test site lies at 34 01'N, 400 m above sea level. The minimum and maximum temperatures are 10.9 C (January) and 32.9 C (June–July). Average annual precipitation, mostly received in winter is 360 mm. The soil is clayey loam with pH 8.5–9.1. After 4 years, the plants attained a diameter of 10 cm. Yield/ha, with the presumption of equal stocking at 2 m × 2 m spacing (2500 trees/ha), was calculated and compared with *Eucalyptus grandis*, *E. tereticornis*, *A. arabica*, and *D. sissoo* that grow in the same area (Table 2).

Another test site, situated 25°23'N, was established in Hyderabad with four varieties of leucaena. Mean minimum and maximum temperatures are 17.3 C and 34.0 C; the soil is fine alluvium; and average annual rainfall is 160 mm. Spacing was 2.75 m × 2 m, with four replications, 30 plants of each variety in each replication. After 2 years, mean diameters at breast height (cm) and heights (m) were K8 (Mexico), 5.6 and 5.7; Peru (Peru), 3.9 and 2.7; Cunningham (Australia) 4.0, 3.0; and local (Philippines introduction) 0.9, 2.0.

A third plantation was established at Peshawar in 1980 at a 2 m × 2 m spacing (Table 3). One variety, K132, performed poorly, with only low survival, and remained a bush.

In another area, recently, survival and growth of *L. leucocephala* were compared with those for five other tree species. An experiment was laid out on 4 February 1982 in a randomized, complete block design, at Lohi Bher (near Islamabad), which has an annual rainfall of 800 mm. The planting was done in pits spaced at 2 m × 2 m; 86 seedlings of each species were planted; and the experiment was replicated five times. Survival rates 3 months later were *Acacia modesta*, 63.95%; *Olea cuspidata*, 96.51%; *Ceretonia siliqua*, 96.51%; *L. leucocephala*, 97.67%; *Acacia aneura*, 87.20%; and *Acacia cyanophylla*, 90.69%.

No significant differences were noted in the

Table 4. Average heights (cm) of four fodder-tree species (8 months old) at five irrigation treatments.

Irrigation	*L. leucocephala*	*R. pseudoacacia*	*L. siliqua*	*T. undulata*
Weekly	371	110	142	100
Every 2 weeks	332	103	123	157
Every 3 weeks	320	85	120	155
Every 4 weeks	294	86	118	146
Nil	267	77	109	141

survival percentage among replications, and all the species performed quite well under the rainfed conditions.

At Peshawar (annual rainfall 360 mm), four fodder-tree species, namely *L. leucocephala*, *Robinia pseudoacacia*, *C. siliqua*, and *Tecoma undulata*, were planted in a split-plot design, with watering at weekly, 2-week, 3-week, and 4-week intervals, and no watering as the first split and species as the second split. Plant and row spacing was about 3 m. The total number of plants in each row was 28. Planting was on 25 July 1981, and watering was done to the end of November 1981, was then stopped, and resumed during March 1982. The results to date indicate no significant differences in survival of the plants under the different water treatments. However, the survival of *R. pseudoacacia* decreased with the increase in the time between watering intervals, and the plants performed poorly without irrigation. In contrast, 100% survival was noted in *L. leucocephala* and *T. undulata* without irrigation.

Although irrigation markedly improved leucaena's performance, this species, even without irrigation, outgrew the others (Table 4). *Tecoma undulata*, which is a species of the arid zone, performed best when unirrigated. Other studies are just beginning, including two investigations of the effect of leguminous trees on the growth and yield of agricultural crops in the experimental gardens of the Pakistan Forest Institute, Peshawar. The study is a follow up to an earlier one (February 1978 – May 1981) in which *D. sissoo*, *E. citriodora*, *Populus deltoides* 63/51, and *Salmalia malabarica* (semal) were planted in a randomized, complete block design, with four replications. Size of the plots was 444 m^2, trees planted at 4.3 m × 4.3 m spacing. The area between trees was sown with wheat in December 1980, and, in May 1981, the average grain yields recorded for plants under *D. sissoo*, *S. malabarica*, *E. citriodora*, and *P. deltoides* were, respectively, 1996, 1802, 1590, and 1532 kg/ha. Yields under *D. sissoo* were significantly ($P < 0.05$) higher than those under the other tree species. The yield from control plots was about 2000 kg/ha.

Wood-Energy Developments in the Philippines

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Substituting wood for oil to produce usable energy is one of the aims of the authorities in the Philippines. In 1979, a dendrothermal power-generation program was launched and, later, a wood-gasification program emerged. To fuel these programs, the government is primarily counting on leucaena, a total 2.5 · 10^4 ha of the crop having been established over the last 3 years. Much has been learned about leucaena in the process: growth characteristics, yield, suitable cultural practices, and the costs of plantation establishment. The information gathered to date is summarized in this paper.

L'un des objectifs des pouvoirs publics aux Philippines est le remplacement des produits pétroliers par le bois dans la production d'énergie électrique utilisable. En 1979, on a inauguré un programme de centrales dendrothermiques, suivi plus tard d'un programme de gazéification du bois. Pour mener à bien ces projets, on compte surtout sur Leucaena dont on a planté un total de 2,5 · 10^4 ha depuis 3 ans. Au cours de ces travaux, l'on a beaucoup appris au sujet de cet arbre : modes de développement, rendements, pratiques culturales appropriées et coût d'établissement des plantations. Cet exposé résume les informations recueillies à ce jour.

La substitución del petróleo por madera en la producción de energía utilizable es uno de los propositos de las autoridades filipinas. En 1979, se emprendio un programa de generación de energía dendrotérmica y, mas tarde, un programa de gasificación de madera. Para estos programas, el gobierno cuenta básicamente con la leucaena; un total de 2,5 · 10^4 ha del cultivo han sido establecidas en los últimos 3 años. Mucho se ha aprendido sobre la leucaena en el proceso: características de crecimiento, rendimiento, prácticas apropiadas de cultivo y costos de establecimiento de la plantación. En este trabajo se resume la información recogida hasta la fecha.

An estimated 200 kWh of solar energy, on average, reaches every square metre of land in the Philippines annually. At 3.2×10^6 ha total area, the sun's energy impinging on the nation during a year is about 64×10^{13} kWh. On an equivalent-energy basis, this quantity is $4 \cdot 10^{11}$ barrels of oil, or more than 5000 times the current yearly oil imports.

Trees may capture and store, in a usable form, 1% or more of the sun's energy. The Philippines has embarked on a major effort to produce fast-growing, leguminous trees as a means for capturing, in usable form, a portion of this renewable energy. This paper provides a brief overview of the developments in the early years of the effort.

Wood-Energy Systems

The Philippines' wood-energy efforts started with the initiation of the dendrothermal power-generation program in late 1979. The objective of this program is to generate economically priced electricity from a locally available renewable resource for the rural areas. A project consists of a:

- Tree farm;
- Wood-transport system; and
- 3-MW wood-burning, electric-power plant.

The target is to have 200 MW of capacity installed by 1987 to meet about 20% of rural-electricity needs at that time.

As initial results of dendrothermal operations became known and there developed an understanding of the potential contribution of wood to national-energy needs, a search ensued for means of substituting wood-derived energy for oil in applications other than electricity generation. As a result, a wood-gasifier program has emerged.

Wood, as such, is not a convenient energy source for many applications that have traditionally relied on oil. However, wood may be converted to a combustible gas that, despite its relatively low kilojoule content, may be directly substituted for oil as a fuel for use in both internal-combustion engines and industrial and other boilers. A program has been adopted to convert major portions of the public transport and small fishing-boat fleets to wood-fueled (gasifier) operations before the end of this decade.

As supplies of wood become available from the newly established tree farms, widespread use of charcoal for industrial, process-heat purposes is envisaged.

Wood, as yet, is not a significant source of energy for use in replacing oil. However, the programs have progressed: the technology has been demonstrated, and the economic advantages have been at least partially verified.

About 1.0×10^4 ha of leucaena (locally ipil-ipil)[1] have been planted in support of the dendrothermal program. Seventeen power plants have been ordered, 11 delivered, and construction has started on 8. Four power plants are to be commissioned during December 1982. The first power from the plants will be fed to the rural electric grids in early 1983.

Approximately 1000 gasifier units have been manufactured, and perhaps 60% of these are in operation. Initial units are being used, primarily, to process fuel for irrigation-pump engines, small buses, and fishing boats. Pilot units are also fueling rice threshers, small ice plants, and electricity-generation plants. A number of charcoal kilns are in operation; however, the charcoal industry must still be expanded and developed.

Tree farms covering about 1.5×10^4 ha have been planted to provide wood for applications other than the dendrothermal program. Almost all of these plantings are leucaena. Experience has shown that reasonably good-quality leucaena plantings, with current technology, will give a yearly yield per hectare of end-use energy equivalent to that obtained from about 30 barrels of oil. Thus, current plantings can substitute for up to about 500 000 barrels of oil annually.

[1] A few hectares of other species have also been planted.

Tree-Farming Experiences

Three years ago, when tree planting was first starting, there were a variety of ideas as to approach and rather limited data on which to base yield expectations. By trial and error, much has been learned after 3 planting seasons, especially about cultivation practices and yield.

Cultivation Practices

Where soil conditions are reasonably favourable for the growth of leucaena, the cultivation steps that produce good results at relatively low cost are to:

- Cut existing vegetation during the dry season; lay cut materials flat on ground and burn;
- Plant seeds at 1 m · 1 m within 2 weeks of the onset of rains; and

Bare-root seedlings are planted in areas not well suited for leucaena and in cogon-infested areas

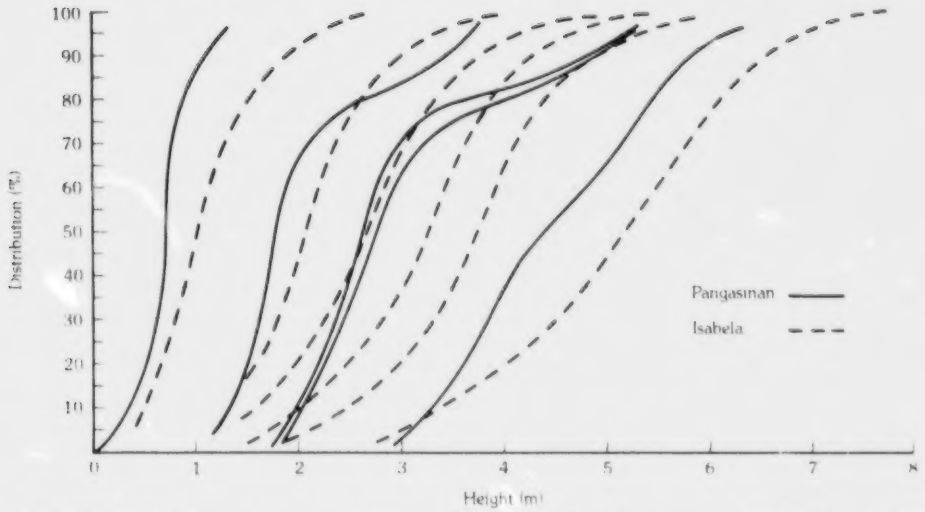

Fig. 1. Height distribution of trees sampled in two plantations — Pangasinan, at ages 4.5, 6.5, 8.5, and 12.5 months, and Isabela, at ages 3.5, 5.5, 7.5, 9.5, 11.5, and 13.5 months

- Weed 3–4 times until the plants are 1–1.5 m tall (4–6 months).

Timely planting (very near the onset of rains) and intensive weeding are necessary for high survival rates and good initial growth.

If an area is not well suited to leucaena, or if cogon predominates in the area, it may be desirable to plant seedlings produced in a nursery. There are mixed views as to whether such expensive transplanting is necessary. The cultivation practices favoured are:

- During the dry season, clear an area 30–40 cm in diameter and dig the cogonal roots to a depth of 15 cm. Place cut cogon flat on cleared area as a mulch.
- Transplant bare-root seedlings (20–25 cm) during the first 6 weeks of the rainy season; and
- Weed the originally cleared patch at least every 6 weeks.

In 1982, plowing was tried, in areas where slopes and rocks permitted it, as a means to reduce weeding costs. My colleagues and I at the National Electrification Administration hope that good results will be obtained but have not yet reached any conclusions.

In general, we have tried to avoid the use of fertilizer. In a few locations where growth was bad, we have found an excellent response to fertilizer application. As yet, however, we have little in the way of systematic observations. Some of the farm managers say that the growth "spurt" after fertilization is short.

Growth and Yield Results

Although results have by no means been uniform, our experiences indicate that leucaena will produce acceptable yields of wood in large areas of the country if care and attention are given to cultivation. Acceptable yield is defined in terms of expected income to the farmer on a 10-ha plot. The lower boundary for acceptable annual yield is 25–30 t/ha on a wet-weight basis. Average growth rates (height) of 20 cm/month (during the 1st year) at 10 000 trees/ha will result in yields in the acceptable range.

Three factors clearly influence growth rates:

- Care and cultivation;
- Soil acidity; and
- Available moisture.

Proper clearing and very intensive weeding are necessary for both survival and good growth. For example, about 40 work days/ha are required for weeding during the first 4–6 months of tree life.

Some data have been collected on cumulative distribution of tree heights for a sequence of tree ages from a tree farm in western Pangasinan and from a farm in the eastern part of the country (Isabela Province) (Fig. 1). Western Pangasinan receives rains only from

the southwest monsoon and has a pronounced dry season from December through May. Isabela receives rains from the west and east (northeast monsoon) and has a short, dry season. The average growth rate for 17.5 months in Pangasinan was 24 cm/month, whereas the figure for Isabela was 36 cm/month. However, during the rainy months, growth in both locations was about 50 cm/month. The annual difference is accounted for by the very slow growth (2 cm/month) in Pangasinan during the dry season compared with a tolerable figure of 11 cm/month in Isabela.[2]

Through age 27 months, the giant leucaena shows a remarkably uniform rate of growth in height and diameter. The median ratio of height to diameter is consistently very close to 170 : 1 during this age span. Monthly growth rates in height and diameter show almost no sign of slowing at least through 24 months. This, of course, means a geometric increase in the rate of volume growth.

Soil Acidity

We have begun to measure soil pH for our tree farms, using portable soil-analysis kits. Because we have inexperienced technicians using these kits, some measurements may not be accurate. Only surface-soil samples have been taken; the maximum distance between a tree used for growth measurements and the soil sample area would be 1.5 m. We will upgrade our soil analysis in the future. Nonetheless, a strong relationship has emerged between growth and the pH measurement for the soil. Of interest is that a fairly significant number of trees grow quite well where the pH is low.

Development Costs

The tree farms being developed in the Philippines employ highly labour-intensive techniques. The development is done by a farmers' association operating on a collective basis. The farmers own the trees and are given a government loan to develop their farms. Labour costs are low (about US$ 1.60/day).

Our experience is that it takes no more than US$ 400–500/ha to develop the trees to maturity (4 years). This amount includes a subsistence allowance for the farmers. At the same time, at least another $ 300–350 would be required to ensure enough inputs so that the trees will prosper.

These are a few of the preliminary conclusions and findings. We hope to produce extensive, definitive reports during the course of the next year.

[2] All of the figures are measured for the median or 50th-percentile tree.

Promotion of Giant Leucaena in Eastern and Southern Taiwan

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The pulp industry in Taiwan has rapidly developed during the past few years, and it is constantly searching for ways to produce inexpensive raw materials from local forest, to substitute for the more than 1 · 10⁶ t of pulpwood being imported annually. Recently the search prompted government and industry initiatives to conduct adaptation, yield, and establishment trials of some new promising species. The quality of pulp from the wood was also tested, and giant leucaena proved superior in both growth and pulping characteristics. Since 1979, therefore, some pulp-and-paper companies have offered farmers a variety of funding schemes to promote afforestation. An area of 2.0 · 10⁵ ha is eventually expected to be used for such schemes, and about 9 · 10⁴ ha have already been planted. The companies cooperate with the farmers, subsidizing operations, extending loans, guaranteeing purchases at an agreed price, etc. The schemes should be profitable for the forest farmers, and a greater profit can be expected when coppicing regeneration is used in second- and third-rotation cycles. Because of leucaena's role in soil and water conservation, its promotion in Taiwan is acknowledged to be advantageous to all the people in the country.

L'industrie de la pâte de bois a enregistré une expansion rapide depuis quelques années et doit s'efforcer de trouver dans les ressources forestières locales des matières premières moins coûteuses que la pâte qu'elle importe annuellement au rythme de plus de 1 · 10⁶ t. Ces efforts ont inspiré aux pouvoirs publics et à l'industrie diverses initiatives sous forme d'essais d'adaptation, de production et d'implantation de quelques nouvelles espèces forestières prometteuses. On a également comparé la qualité des pâtes de bois, et le Leucaena géant a démontré sa supériorité tant pour la rapidité de sa croissance que pour la qualité de la pâte obtenue. En conséquence, depuis 1979, des sociétés de pâtes et papiers ont offert aux cultivateurs divers modes de financement pour la création de boisements. On estime à quelque 20 000 ha les superficies qui pourront être affectées à ces fins, dont 9 · 10⁴ ha ont déjà été plantés. Ces sociétés collaborent avec les cultivateurs en subventionnant leurs travaux, en leur faisant des prêts, en garantissant le prix d'achat de leurs produits, etc. Ces arrangements devraient être rémunérateurs pour les sylviculteurs et l'on peut espérer des profits accrus lorsqu'on procèdera au recépage aux deuxième et troisième cycles de rotation. En raison des avantages de Leucaena pour la conservation du sol et de l'eau, l'encouragement qu'on lui accorde à Taiwan est reconnu comme devant profiter à l'ensemble de l'économie.

En Taiwan la industria de pulpa se ha desarrollado rapidamente en los ultimos años y busca constantemente formas de producir materias primas baratas a partir de los bosques locales, para substituir mas de 1 · 10⁶ t de pulpa de madera importada anualmente. Recientemente, la busqueda motivo iniciativas oficiales e industriales para realizar pruebas de adaptacion, rendimiento y establecimiento de algunas nuevas especies promisorias. Se probo la calidad de la pulpa de la madera y la leucaena gigante demostro ser superior tanto en crecimiento como en caracteristicas de la pulpa. Desde 1979, por tanto, algunas companias de pulpa y papel han ofrecido a los agricultores una variedad de planes de financiamiento para promover la reforestacion. Se espera que finalmente un area de 20 000 ha sea empleada para tales planes, y cerca de 9 · 10⁴ ha ya han sido plantadas. Las companias cooperan con los agricultores, subsidiando sus operaciones, otorgando prestamos, garantizando compras a un precio acordado, etc. Los planes deben ser rentables para los agricultores y se puede esperar un mayor beneficio economico cuando la regeneracion se use en el segundo y tercer ciclo de rotacion. Debido al papel de la leucaena en la conservacion de suelo y agua, su fomento en Taiwan sera ventajoso para toda la poblacion.

To meet the ever-increasing wood demands in Taiwan, the Taiwan Forestry Research Institute introduced giant leucaena from the University of Hawaii in 1975 and evaluated the tree's adaptability. The results from the initial experiments were excellent, and a surprisingly good annual growth rate was achieved through very dense plantings.

Current interest in giant leucaena is clear from several developments: in the industrial sector, the Chung Hwa Pulp Corporation (CHP) and the Formosa Chemicals and Fibre

Corporation (FCFC) imported seeds from the Philippines and, since 1979, have been promoting plantations. The Ministry of Economic Affairs and the related organizations have organized a liaison group for the research and development of giant leucaena, and the Council for Agricultural Planning and Development initiated an intermediate experiment study plan, which is being implemented, step by step, beginning in July 1980. The Department of Agriculture and Forestry of the provincial government has taken responsibility for the promotion of research achievements and, for example, has included giant leucaena as one of the items eligible for coverage within the loans and assistance rendered to the Hualien county government and CHP for a joint seedling raising project.

Together, Taitung and Hualien counties have a land area of $8.14 \cdot 10^5$ ha, of which $7.92 \cdot 10^5$ ha is sloping land; a good portion ($3.2 \cdot 10^4$ ha) of the sloping land could be used for giant leucaena (Table 1). Along with acting as an erosion control, the trees could provide raw material, for example, to the CHP pulp factory. The annual demand for pulpwood in Taiwan is about $1.3 \cdot 10^6$ t and is expected to rise to $2.2 \cdot 10^6$ t in the near future. However, the raw material available domestically is only $2.5 \cdot 10^5$ t/year, or only 19.23%. Thus, the pulp-and-paper industry has been focusing on the promotion of giant leucaena plantations (Table 2) in the hope that it can eventually achieve self-sufficiency.

Various pulp-and-paper companies have begun cooperating with farmers in an effort to achieve their planting targets. Some provide funds to forest farmers on a contract basis, whereas others share the wood harvests on a mutually agreed ratio. Still others enter lease arrangements for privately owned forestland or lands for afforestation. In other words, they are following as many avenues as possible.

Promotional efforts by CHP focus on tree farmers and related organizations and groups, with the company providing seeds and seedlings and a monetary award (US$ 100/ha) for those who achieve 70% survival among their seedlings at 3 months after planting. CHP is also working with the Council for Agricultural Planning and Development, which administers a loan plan for rural reconstruction, to extend, to farmers, loans (up to US$ 1000/ha) at a preferential interest (2% lower than the banks' current rates).

The price that CHP is willing to pay for logs

Table 1. Estimate of the area for establishment of leucaena in the eastern part of Taiwan.

Hualien County		Taitung County	
District	(ha)	District	(ha)
Hsiu-Lin	1173	Chang-Pin	1800
Chi-An	165	Cheng-Kong	750
Shou-Fong	4724	Tong-Ho	1400
Fong-Lin	1308	Chi-Shang	600
Wan-Jong	523	Hai-Tuan	400
Kwang-Fu	1593	Kuan-Shan	600
Jueh-Shue	1336	Lu-Yeh	400
Yu-Li	2976	Yien-Ping	850
Chuo-Chi	2260	Peh-Nan	1200
Fu-Li	2280	Tai-Ma-Li	1100
Fong-Ping	3616	Jin-Fong	100
		Ta-Wu	200
		Ta-Jen	600

Table 2. Targets and progress of promotion of giant leucaena by various pulp and paper companies.

	Area (ha)					
Company	1980	1981	1982	1983	1984	Planted[a]
CHP	500	1000	2000	2000	2000	3671
YFY[b]	200	1000	1000	800	—	1000
FCFC	1100	2200	2600	2300	1800	4510

[a] CHP, since May 1979; YFY, since January 1980; FCFC, since April 1979.
[b] YFY, Yuen Foong Yu Paper Mfg. Co. Ltd.

delivered to its factory sites is 10% of the price of the pulp, ex factory, on the domestic market. The price for uncut stands is 4% of the pulp price.

YFY (Yuen Foong Yu Paper Manufacturing Company Ltd) has opted for a closer partnership with the tree farmers. The farmers provide land, and the company manages afforestation, weeding, cutting, and transportation. At harvest, all the production costs are deducted from the wood income, and the remainder is shared between the farmers and the company on the basis of the rotation cycle: first harvest — equal distribution; second — the farmers take 45%. The portion of logs that the farmers are entitled to will be bought by the company at a guaranteed price. YFY also leases some land in Taitung for afforestation purposes.

FCFC operates two schemes: loans and harvest sharing. Within the loan scheme, the company provides seeds and assets, and the tree farmers supply land and labour in a joint venture. When the trees have grown to 30 cm, with a survival rate above 80%, a loan (US$ 1750 ha) is extended to the farmers on the basis of their needs. The loan amount is converted to its equivalent in standing logs (the total is divided by the log price prevailing at the time that the loan is made). This quantity will be deducted from the total weight of logs at the time of felling, and the farmer's share of what's left will be purchased by the company at a guaranteed price.

In the harvest-sharing scheme, the tree farmers provide the land (including any land they have rented from the government), and FCFC manages afforestation. After the trees have grown, both parties share the yield: 30% for the farmer and 70% for the company.

On land leased from the government, a monetary amount equivalent to 20% of the total harvest goes to the government. The harvest-sharing rate between the farmers and the company is 15% and 85% during the first rotation and 20%, 80% during the second cycle. And the portion the tree farmers are entitled to share will be purchased.

The price of standing logs at the forest was set at US$ 15 t during the third quarter of 1980. Thereafter, adjustments have been made at each quarter according to the price index published in the monthly reports of the Executive Yuan. In other words, the arithmetic mean from the general index will be used in each quarter to serve as the index base for the next spring (based on this calculation, the purchase price in the first quarter in 1981 was US$ 16.3 t of standing logs).

The afforestation costs involved in establishing a new plantation of giant leucaena are quite different from those involved in maintaining coppicing stands. The newly established plan-

Table 3. Costs for establishing new plantations and tending coppicing stands of giant leucaena in Taiwan [a]

	Quantity	Unit	Unit price (NT$)	Fund (NT$)	Remarks
1st year					
Land preparation	25 *5*	Working days	400	10000 *2000*	Sloping land is assumed
Planting	20	Working days	400	8000	Daily 250 plants worker
Weeding	20 *20*	Working days	400	8000 *8000*	2 times year
Overhead cost	15	%		3900 *1500*	Including workers' shacks, traveling costs
Seed	1.5	kg	400	600	
Seedlings	5000	each	1	5000	
2nd year					
Weeding	10	Working days	400	4000	
Overhead cost	15	%		600	
Total				40100 *11500*	

[a] Figures in italics are for coppicing stands.

Table 4. Establishment costs (NT$/ha) for plantations of giant leucaena from direct seeding, bare-root seedlings, and seedlings in plastic bags.[a]

	Direct seeding	Bare-root seedlings	Seedlings raised in plastic bags	Remarks
Sloped land				
Kaohsiung	18475	—	—	
Pin-Tung	—	—	32784	
Tai-Tung	16736	17427	—	
Hualien	41404	51255	—	Weeding 3–4 times/year
Paddy field				
Kaohsiung	26502	34300	—	
Flat land				
Chia-Yi	—	—	25178	
Tai-Nan	—	—	25151	
Kaohsiung	—	—	34020	
Tai-Tung	17575	21575	—	
Riverside				
Chia-Yi	—	—	18442	Seedling cost is high (NT$ 2 each)
Tai-Tung	12500	—	—	Poor irrigation facilities so irrigation costs high

[a] After 1 year, one weeding was conducted in the forest areas. At an average 12–15 days of labour (NT$ 350/day), the total weeding cost comes to NT$ 4200–5250/ha.

tation includes costs for seedlings, transportation, land preparation, planting, and 3–4 weedings, whereas the coppicing stands need 2–3 weedings only. The new plantation with 5000 seedlings/ha and 3–4 weedings would cost NT$ 34 500 (US$ 862.50)/ha, whereas the coppicing stands cost NT$ 11 500 (US$ 287.50)/ha (Table 3).

Kiang (1981) collected data on new plantation costs from various places on the island and computed the direct afforestation costs (Table 4). The data indicated that the methods employed in afforestation directly influence costs. Commonly, seedlings in plastic bags are planted, but this method was shown by Kiang to be the highest-cost planting method, with direct seeding being lowest and bare-root planting being intermediate. Studies showed that bare-root plantings seldom fail in the eastern part of Taiwan but, in the southern part, are rarely used.

Kiang (1981) also analyzed the potential profits from afforestation with giant leucaena, and, on the basis of a total cost of NT$ 46 700/ha, deducted the monetary afforestation award (NT$ 5500: CHP pays NT$ 4000 and the government subsidizes this amount with $1500) to arrive at the total direct cost (NT$ 41 200). If the annual interest rate is 15%, compounded annually, the total interest to be paid is NT$ 21 460. At the time of the first harvest (3 years), the total cost, excluding the land rentals, is about NT$ 62 660, and about 105 m^3/ha can be harvested at a value of NT$ 700/m^3 (NT$ 73 500/ha).

Thus, the profit would be NT$ 10 840. If the land has been rented, rental costs would be 20%, i.e., NT$ 14 700. In other words, the tree farmers would lose NT$ 3860. However, if the rental standards of the Land Bank of Taiwan (i.e., $400/year) are adopted, a net profit should be available. After the first cutting, renewal is by coppicing.

In the establishment of giant leucaena plantations, great emphasis must be laid on the plantation costs and production capacity in a unit area. Planting density and periods of rotation are the most important factors. During the initial stages of plantation promotion in Taiwan, it was believed that dense plantings (8000–10 000 trees/ha) would produce the highest output. However, according to field observations since, even 8000 trees/ha is too dense for pulpwood production.

Fast-Growing Leguminous Trees in Sabah

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The importance of high growth rates of trees in the tropics is highlighted, particularly in relation to the future demands for wood products in Asia. In Sabah, Malaysia, the need for high volumes of wood and for tree legumes in reclamation of land degraded by excessive cultivation has prompted tree planting and trials with two major species: Acacia mangium and Albizia falcataria. Two other species, Acacia auriculiformis and Gliricidia sepium are mentioned, the latter grown primarily for its value as cocoa shade in the state. Special attention is drawn to the importance of seed origin and the dangers of overexpanding populations of limited genetic base. The biological ease with which some species can be generatively or vegetatively propagated makes overexpansion a real possibility.

On souligne ici l'importance des arbres à croissance rapide pour les Tropiques, en considération, surtout, de la demande prévisible des produits du bois, en Asie. Dans le Sabah (Malaisie) cette nécessité a stimulé le recours à des arbres de la famille des légumineuses pour la régénération des terres ruinées par une exploitation agricole excessive, et notamment les essais de deux espèces principales : Acacia mangium et Albizia falcataria. On mentionne également deux autres espèces : Acacia auriculiformis et Gliricidia sepium, cette dernière précieuse surtout pour ombrager les plants de cacao dans l'État. On attache une attention spéciale à l'origine des semences et aux dangers d'une expansion excessive de populations n'ayant qu'une base génétique limitée. La facilité biologique avec laquelle certaines espèces peuvent se propager par voie végétative ou générative rend très réelle la possibilité d'expansion exagérée.

Se subraya la importancia de las altas tasas de crecimiento arbóreo en los trópicos, particularmente en relación con las demandas futuras por productos madereros en Asia. En Sabah, Malasia, la necesidad de mayores volúmenes de madera y de árboles leguminosos para recuperar la tierra degradada por exceso de cultivo ha promovido la siembra de árboles y los ensayos con dos especies mayores: la Acacia mangium *y la* Albizia falcataria. *Se mencionan otras dos especies,* Acacia auriculiformis *y* Gliricidia sepium, *la última nombrada principalmente por su valor como sombrío del cacao en la provincia. Se llama la atención sobre la importancia del origen de la semilla y sobre los peligros de la sobreexpansión de poblaciones con base genética limitada. La facilidad biológica con que algunas especies pueden ser propagadas generativa o vegetativamente hace de la sobreexpansión una posibilidad real.*

Tree legumes have a dual role in tropical farming and plantations in Malaysia: reclamation of degraded land and wood production, both of which are becoming increasingly important in Sabah.

Initial studies on tree planting were aimed at finding species and developing silvicultural techniques to reclaim the derived grasslands abandoned after shifting cultivation or, on the Sook plain, probably resulting from a massive natural fire (Cockburn 1974). The Forest Department commenced trials in the mid-1950s. These were intensified a decade later when it was recognized that species were also needed for some logged-over forest areas that did not respond to natural-regeneration management. At this time, the popular species for tropical tree planting, especially on grassland sites, was *Pinus caribbaea*, whereas fast-growing hardwoods such as *A. falcataria*, *Gmelina arborea*, the eucalypts, etc. were acknowledged as productive species on better sites.

The pines were regularly set back by fires, inevitable in grasslands. Hardwood firebreaks were planted, and the most common species used was the ubiquitous, but poorly formed, *Acacia auriculiformis*. A second acacia *A. mangium*, a species having a distinct bole, was introduced. A small quantity of seed, collected from a single tree, was imported from Queensland, Australia, in 1966 and planted in 1967. Seeds produced in 1971 were used for further firebreaks and Tham (1980) observed: "... by 1975 it was apparent that the species ... was outgrowing the pines on these degraded sites."

Albizia falcataria featured in planting trials from 1960. It occurs in many parts of Sabah, planted mainly as an amenity tree but probably introduced as a shade tree. J.A. Hepburn

(personal communication) suggested that the species is native to Sabah. When tobacco was grown in the northwest, *A. falcataria* was used as shade and as fuel for curing the leaves. Like *A. auriculiformis*, it has a notoriously poor form, attractive to landscape planners but problematic for utilization.

The natural distribution of *A. mangium* in Australia is described by Nicholson (1981), and Pedley (1978) recorded it in southern Papua New Guinea and the Moluccas Islands. Tham (1980) placed the northern limit of distribution at 0 50'S at Monokwari in Irian Jaya; the southern limit recorded by Nicholson (1981) is Herbert River Valley, Queensland, Australia, 18 31'S. The natural habitat of *A. mangium* appears to be low-lying land liable to inundation. It occurs with *Melaleuca* spp. in Queensland on the landward fringes of the mangrove forests. Land clearing, especially by fire, influences the local distribution, and *A. mangium* appears to be a pioneer species. It can also be considered a riverine species, occurring abundantly in the riverside forests between Ingham and Mossman on the eastern side of the dividing range. In fact, though normally a lowland species, it may have encroached on the hills through valleys and is found at 720 m altitude in Gadgarra Forest Reserve, Queensland.

Taxonomically, *A. mangium* belongs to the Mimosoideae and is in the section Juliflorae of the subgenus *Heterophyllum*. It is a phyllode-bearing acacia. Upon germination, a single compound leaf (pinnae), usually bearing six pinnules, develops above the cotyledon. At the next 2 – 4 nodes, a bipinnate leaf is formed. Double bipinnate leaves form on successive nodes and transform into phylloces. Under nursery conditions, phyllodes are being formed by the 5th or 6th week. The characteristic nodules begin to form on the roots at about the same time. Seedlings tolerate shade or full sun, although observation suggests that light shade for up to 2 weeks is beneficial and full sunlight is preferred thereafter.

Flowers are milky white, borne on a loosely packed spike (53 flowers/cm — Bowen 1981). The corolla is very small, and the androecium gives the flower colour and form. Inflorescences are borne in clusters of 2 – 6 in the axil of phyllodes, and, at peak flowering, the tree is a mass of blooms. Flowering is precocious, frequently occurring at age 18 months. Most acacias are outbreeding by preference (Moffett and Nixon 1974); therefore, controlled pollination can be effected without emasculation. There is some evidence in Sabah that self-fertilization is possible, but cross-pollination is most common.

Narrow pods (3 – 5 mm wide) develop and intertwine into characteristically tight ball-like structures. The seeds are oriented along the pods. In Sabah, it has been found that first-generation trees have well-synchronized flowering, and there is always a single annual peak, although synchronization is less in subsequent generations. Pod ripening is indicated by a change from green through brown to black. On ripening, pods dehisce along one margin, and the seeds, also black when ripe, hang outside on the colourful orange funicles, another characteristic of many acacias. Harvesting takes place between late April and mid-August, pods ripening approximately a month earlier on the west coast than on the east.

The potential of this species has been recognized by the United States National Academy of Sciences, which sent a panel of scientists to Sabah in May 1981. Their visit has resulted in the preparation of a document on the species (NAS, in press).

Many albizias are grown as shade trees for cash crops, and they are especially favoured for tea shade in widely separated countries such as Fiji, Sri Lanka, and Kenya. According to Fenton et al. (1977), *A. falcataria* has been planted in forestry trials or plantations in at least 14 countries. Tropical foresters appear to "blow hot and cold" over the species, probably because of its outstanding performance at establishment and growth, which are offset later by its poor form and inability to withstand winds. However, Streets (1962) pointed out that the species, indigenous to Moluccas, has been distributed throughout the Far East since the 1870s, describing it as "A very large, fast growing tree, with light crown and clean straight bole." The wide distribution in the tropics is artificial, and records quoted by Fenton et al. (1977) suggest that it regenerates readily on disturbed land.

The tree belongs to the subfamily Mimosoideae. It has compound leaves, and flowers are borne on fairly large panicles. Like *A. mangium*, the androecium is the attractive part. Flowering appears to be synchronous in Sabah, and, during 2 – 3 weeks, the crowns of mature trees are covered with flowers. It is unusual for trees to flower before they are 6 years old, and full flowering is unlikely to occur before 10 years.

The flat woody pods are about 10 cm long and 2 cm wide, with the 11 or 12 seeds arranged laterally. The ripening period is extremely short, and, because the pods dehisce along both margins, harvesting must be carefully planned. Seeds are normally collected in May; a few trees flower again in October, but little or no seed can be harvested.

Although *A. mangium* and *A. falcataria* are the only species planted commercially in Sabah, there are two other species worthy of note, i.e., *A. auriculiformis* and *Gliricidia sepium*. Both are planted throughout the state, the former mainly as an amenity species, the latter for cocoa shade.

Acacia auriculiformis grows naturally from northern Queensland and the coast of western Australia into Papua New Guinea where it overlaps with *A. mangium*. It is also found in the Solomons. Like *A. falcataria*, it has been planted in many tropical countries. Generally, it has a very poor form, but its high wood density (0.60–0.75) makes it a useful fuelwood. In the natural forest, some well-formed trees can be found with straight boles of 15 m or more.

Flowers are yellow and, otherwise, are similar to those of *A. mangium*. The species flowers precociously, setting large quantities of seed. The fruits are twisted pods shaped like a human ear, hence the specific name; they often develop close to one another but do not intertwine. Seeds are arranged laterally across the pod and hang outside on yellow funicles after the pod dehisces along one side.

It is difficult to describe the natural distribution of *G. sepium* because it has been introduced into many countries in Asia, Africa, Central and South America. It produces an attractive flower, is easily set from root cuttings, and is, therefore, popular among gardeners throughout the tropics. It can be planted as a live fence, repeatedly pollarded for fuel, and is a valued fodder and a green manure. These attributes have led to its indiscriminate and wide distribution.

The species is also widely used for shade in cocoa plantations, and, as cocoa has become the most popular cash crop in Sabah (before 1970 only $2.5 \cdot 10^3$ ha were planted but by 1981 the figure was more than $50 \cdot 10^3$ ha), *G. sepium* is the most extensively planted tree legume in Sabah. It is seldom raised from seed, cocoa planters preferring hardwood cuttings, about 0.5 m long and 2–3 cm in diameter. On cleared forest sites, mortality is low but, on badly disturbed areas, the cuttings fail unless the planting hole is carefully prepared and a low concentration of rooting hormone is applied (M. McMyn, personal communication).

Field Trials and Growth Rates

In Sabah, research on species introduction and silviculture is carried out by the state forest department, whereas all plantings are entrusted to other agencies such as the Sabah Forest Development Authority (SAFODA), which is a government-controlled body responsible for afforestation. Sabah Foundation, a self-funding government organization established to ensure education facilities and other social improvements for Sabahans, has entered two joint ventures involving major forest tree planting. One, called Sabah Softwoods Sdn Bhd, is with the North Borneo Timber Company and the other, Pacific Hardwoods Sdn Bhd, is with Weyerhaeuser Company. The former plans to plant just over $6 \cdot 10^4$ ha of forest trees, and the latter $1.2 \cdot 10^4$ ha. Since it was formed in 1974, Sabah Softwoods has planted about $2.5 \cdot 10^4$ ha, and Pacific Hardwoods is at the trials stage. SAFODA has established $1.5 \cdot 10^3$ ha, mainly *A. mangium*.

Although *A. mangium* was first planted in 1967, relatively few trials were undertaken before 1980. A spacing trial was established at the Sook research station in 1974, and a further seed importation was planted, also at Sook, in 1978. Meantime, Sabah Softwoods and Pacific Hardwoods planted trials in 1976. UNDP (United Nations Development Programme) sponsored the FAO (Food and Agriculture Organization of the United Nations) Seed Sources Establishment and Tree Improvement Project (MAL 78/009), which was started at the request of the state forest department in 1980 and has since organized many trials.

During 1980, an assessment of form variability, which included growth measurements, was carried out in the older plantings. More seed was imported from individual, though not select, trees from the easily accessible acacia forests of Queensland, Australia. At the same time, arrangements were made for contracts to harvest seed from the remote Iron Range area of Queensland and in the Western Province of Papua New Guinea. These efforts have resulted in a gradual accumulation in Sabah of seed from widely separated sources. A progeny–provenance trial was established on three sites in 1980 and includes a total of 29

progeny and 6 provenances (including the Sabah race).

In 1982, a provenance trial to compare sources south of Mossman in Queensland with the Papua New Guinea provenances was planted by Sabah Softwoods and Pacific Hardwoods, and the Forestry Department established a provenance-resource stand with Papua New Guinea stock. Nursery variation between progeny and provenances is being observed in the successive Sabah generations. Sabah Softwoods planted some of these trials in the field in 1982.

The first recorded trial planting of *A. falcataria* was at Sibuga, near Sandakan, on the east coast in 1960. Seeds were collected locally from amenity trees. This trial has since been felled. Between 1965 and 1969, 14 additional trials were planted on various sites, but only 4 of these have sufficient stocking to be considered as interim seed sources. Sabah Softwoods established *A. falcataria* in its first plantings in 1974 and has planted areas in each succeeding year using seed imported from Sri Lanka. Seeds from selected trees from the Philippines Pulp and Paper Industry (PICOP) Bislig plantations were imported in 1979, and a small plot was planted in 1980 as a provenance-resource trial. This was browsed heavily by deer but was observed to be recovering in 1982. Half-sib progeny seeds from selected PICOP trees were imported in 1981, and a trial was established by Sabah Softwoods in 1982.

The major research field stations are at Sook, Ulu Kukut, and Gum Gum (Fig. 1). Tham (1977) described the Gum Gum site as being a logged-over forest with alluvial soil and the Sibuga site as *I. cylindrica* over degraded red–yellow acrisol (Tham 1980). Data from these sites are complemented by those from

Fig. 1. Map showing research areas in Sabah, Malaysia.

two firebreaks (Jalan Madu and Jalan Lee) at Ulu Kukut, which both traverse a catenary formation on which *I. cylindrica* has become established. The catenary strata are only identified for Jalan Lee. In the Sook area, the spacing trial and the avenue trees are on poor sites but Kampung Bunang is a relatively good site. Data supplied by Sabah Softwoods are from logged-over forest sites that are not really typical of sites within this definition. The Pacific Hardwoods site is compacted ultisol over granodiorite to ultrabasic rock with a pH 6.0.

The plots of *A. mangium* indicate either cessation or marked reduction in height increment with increasing age (Table 1). Height growth at Jalan Madu and Jalan Lee was less than 2 m/year at the time of measurement. Diameter increment appears to fall off with age also but in 8.7-year-old trees, at Jalan Madu, is still 2.4 cm/year.

The influence of age on increment is clear from a comparison of measurements made at Gum Gum. A 9-year-old *A. mangium* tree, 23.0 m high with a DBH (diameter, breast

Table 1. Top height and diameter, breast height (DBH) of *A. mangium*.

Location	Age (years)	Top height (m)	DBH (cm)
Pacific Hardwoods	2.0	7.5	7.9
Kampung Bunang	2.9	13.4	14.4
Sabah Softwoods	5.0	21.6[a]	16.0
Sook	5.1	17.1	13.3
Jalan Lee	8.7	16.3	20.7
Sibuga	10.0	23.0	20.0
Gum Gum	11.9	24.8	26.8
Jalan Madu	12.8	20.1	30.2

[a] Mean height of 100 trees with largest DBH/ha.

Table 2. Variation in growth of *A. mangium* (8.7 years) on different soil catenas along Jalan Lee (Low, in preparation).

Catena	Mean height (m)	Mean DBH (cm)
Skeletal	11.0	14.6
Hill creep	14.6	18.8
Sedentary	15.9	19.9
Hill wash	19.5	23.9
Alluvium	20.7	26.5

height) of 22.9 cm, exhibited an annual increment of 2.6 m in height and 2.5 cm in DBH, whereas the respective figures for an 11.9-year-old tree (24.8 m tall and 26.8 cm DBH) were 2.1 m and 2.3 cm. Nevertheless, the growth rates are still good, and, as the wood density is approximately 0.6 (NAS, in press), the production is satisfactory. A 10% sample of the Jalan Lee population (made up of more than 2000 trees) was measured. This firebreak extends nearly 5 km across five catenary strata (Table 2).

The development of soil catenas is important to plant growth throughout the world but is especially significant in the tropics. Soil texture varies little from catena to catena, but soil depth usually increases from the top to the bottom of the slope; in this case, the difference in altitude is less than 100 m and only the alluvial catena is much deeper than the others. Tree growth on the alluvial catena is almost double that on the skeletal catena of the hilltop — a difference that could be extremely important to *A. mangium* wood production.

The effects of three spacings (4.6, 3.7, and 3.1 m) were measured at Sook, and the findings at 5.1 years indicated that the closest spacing increased height growth considerably (mean heights 14.9, 14.3, and 17.1 m respectively) but had little influence on diameter growth (mean DBH 13.8, 13.4, and 13.3 cm).

There are only two reliable estimates of volume production for this species in Sabah: the first, supplied by Sabah Softwoods, is 145 m^3/ha (at 5 years), which translates into a mean annual increment (MAI) of 29 m^3/ha. The second was recorded by Tham (1980) when the Sibuga plantation was felled at 10 years, yielding 439 m^3/ha (MAI 44 m^3/ha). Both figures were to 10 cm top diameter.

The growth of *A. falcataria* is being carefully monitored by Sabah Softwoods, and Tan and I (1982) have reported the data elsewhere. Mean data from soils more than 50 cm deep with more than 20% clay provide some basis for growth comparisons for the species from ages 2–7 years, and other data are available for older trees from the Forestry Department trial plots (Table 3).

The only volume data available (Tan and Jones 1982) for the species in Sabah indicate 225 m^3/ha at age 5 years (MAI 45 m^3/ha). Plots on better sites annually yield 66 m^3/ha.

Wood density of *A. falcataria* at Gum Gum has been recorded by Ong and Tham (1980) as varying between 0.24 and 0.41. Correlations between density and growth rates indicate higher density with better growth rates; however, the correlations are weak.

Seed Supplies

At the beginning of a planting program, seeds often are obtained from the most convenient sources, although research over the last 2 decades has indicated that the origin (provenance) of a particular species may be critical to its success. If the genetic base is limited, a

Table 3. Growth data for *A. falcataria* in Sabah.

Location	Age (years)	Height (m)		Mean DBH (cm)
		Dominant[a]	Mean	
Sabah Softwoods	2	11.5	—	—
Sabah Softwoods	3	19.1	—	—
Sabah Softwoods	4	25.2	—	—
Sabah Softwoods	5	29.4	—	—
Sabah Softwoods	6	32.7	—	—
Sabah Softwoods	7	35.2	—	—
Kolapis	10.4	31.0	26.5	32.5
Gum Gum	11.4	34.0	30.1	35.5
Apas Road	14.4	35.0	24.0	37.1
Lungmanis	14.8	34.0	30.5	47.9

[a] Mean height of the 100 trees/ha with the largest DBH.

precocious, flowering species that is easily propagated can be overextended.

Acacia mangium is an example. A small amount of seed was imported from a single tree to establish the first Sabah generation (fewer than 500 trees in 1967 on three sites) and served as the source for seed for second and third generations. Fourth and fifth generations will have developed by now, and examination of the first, second, and third generations indicated a deterioration in form (Williams et al., in preparation). This degradation was both masked and complicated by the development of an *A. auriculiformis* hybrid (FAO, in press, a).

A new two-pronged breeding policy, therefore, was developed for *A. mangium*, requiring vegetative expansion of selected trees of the original imports and imports of more sources to expand the genetic base. At present, the first generation in Sabah seed is harvested from Jalan Madu, 221 trees, and from Gum Gum, 37 trees; the second generation comes from Jalan Lee, Penuntut, and Siba also at Lungmanis, approximately 4500 trees. It is estimated that the mean annual harvest if properly timed and carefully handled will be 0.5 kg seeds from each tree (Bowen and Eusebio 1981a). During the 1982 harvest season, every effort was made to maximize the first-generation harvest (Bowen and Eusebio, in press); however, shortage of staff and a poor crop combined to reduce the forecast 126 kg to an actual harvest of only 44.5 kg. Likewise, only 101 kg of second-generation seed was harvested because of a shortage of staff. A new seed source is being developed from a second importation, which has been culled to 10% of its original size (3600 trees). The stand is now 4 years old so should be in full production in the late 1980s.

Sabah Softwoods has about 18 ha of culled stands, harvesting more than 80 kg seed in 1981. It has potential for a much larger production, well in excess of its requirements.

Albizia falcataria presents a different problem: reasonable quantities of seed are only available within Sabah from amenity trees. Sabah Softwoods imports all its seed from Sri Lanka. Studies at the Tree Improvement Section of the state research centre and by the Sabah Softwoods tree breeder indicate a generally poor form of trees both from local seed sources and from exporters. However, excellent trees occur in the Philippines (Jones 1981), and there is evidence that selection will improve form. Attempts are being made to establish seed sources in Sabah from outstanding individuals and also from seed imported from the Philippines. Unfortunately, the species will take 10 years to become productive. Efforts are being made to propagate flowering individuals vegetatively, but this is difficult. There is a possibility that vegetative propagation of juvenile material for commercial planting will be an answer to these problems (FAO, in press, b).

Acacia auriculiformis seed is readily available from amenity trees, but the form is very poor. Like *A. mangium*, this species probably has suffered from an overexpansion of a limited genetic base. Seed has now been imported from western Australia and ordered from Papua New Guinea.

Gliricidia sepium develops into a shrub of up to 10 m on good, often volcanic, sites in the south. However, it is normally smaller than this. Its wide, artificial range, coupled with its easy propagation, especially by cuttings, suggests the need for survey of its natural habitat to ascertain its potential beyond that of shade or fuelwood.

Conclusions

Tree legumes are important in Sabah both for the rehabilitation of land degraded by overintensive agriculture and for the production of wood raw material. *Acacia mangium* has shown itself capable of growing, and growing quite well, on degraded and disturbed sites. However, the current population of this species in Malaysia is from a limited genetic base. The quality and health of this population need careful monitoring while efforts are being made to expand the gene base. Ample seed of improved quality for the state needs is available at present, and other sources are being developed. The need and the means for improvement of the form of *A. falcataria* have been identified, and efforts are being made to develop within-state sources. Both *A. auriculiformis* and *G. sepium* have potential, and the latter is widely planted as shade for cocoa. No research is planned for either species, although potentially better-quality seed of *A. auriculiformis* has been and is being imported. Sabah is fortunate in having an expanding plantation program, as rapid forest exploitation continues. There is every possibility that a continued raw-material resource will be available for either export or local processing.

Growth Data from Sabah Softwoods Sdn Bhd Plantations of Some Fast-Growing Leguminous Trees[1]

Tan Kee Chong *Sabah Softwoods Sdn Bhd, Brumas, Sabah, Malaysia*

In 1974, Sabah Softwoods Sdn Bhd was created to manage a 6.0 · 10³ ha afforestation program; to date, it has planted 2.3 · 10³ ha, some of which include Albizia falcataria, Acacia mangium, *and* Leucaena leucocephala. *Data on height and diameter are being collected, and preliminary indications are that* A. falcataria, *planted at 600–900 stems ha is sawlog class by age 8 years; that, at the same spacing,* A. mangium *has a mean annual increment in volume equal to 30 m³ ha, and that liming is essential in the soils of Sabah where* L. leucocephala *is grown but is regarded as uneconomic.*

C'est de 1974 que date la fondation de la Sabah Softwoods Sdn Bhd, en vue de mettre en oeuvre un programme de boisement de 6.0 · 10³ ha. Jusqu'à present, on a effectue la plantation de 2.3 · 10³ ha, en partie avec Albizia falcataria, Acacia mangium *et* Leucaena leucocephala. *On s'occupe à relever les hauteurs et les diamètres obtenus et les premiers resultats indiquent que* A. falcataria *plante à raison de 600 à 900 pieds ha atteint les dimensions de sciage dès l'âge de 8 ans ; qu'à la même densité,* A. mangium *produit une augmentation volumétrique annuelle equivalente à 30 m³ ha ; et que le chaulage est essentiel dans les sols du Sabah, où l'on cultive* L. leucocephala, *que l'on considère comme non économique.*

En 1974 se creo Sabah Softwoods Sdn Bhd para administrar un programa de forestacion de 6.0 · 10³ ha. Hasta hoy dia se han plantado 2.3 · 10³ ha, algunas de las cuales incluyen Albizia falcataria, Acacia mangium *y* Leucaena leucocephala. *Los datos de la altura y diametro estan siendo recogidos, y las indicaciones preliminares son que la* A. falcataria, *plantada a 600–900 troncos ha es del tipo aserradero hacia los 8 años, y que al mismo espaciamiento la* A. mangium *tiene un incremento promedio anual en volumen de 30 m³ ha, y que la cal es esencial en los suelos de Sabah donde se siembra* L. leucocephala *pero se la considera no economica.*

The data in this paper were assembled by T.J. Wormald, research consultant to the company, as an update to data quoted in Tan and Jones (1982).

Sabah Softwoods Sdn Bhd is a joint venture between Sabah Foundation and North Borneo Timber Company formed in 1974 for a 6.0 · 10³ ha afforestation program. Up to mid-1982, 2.3 · 10³ ha had been planted, mainly with fast-growing hardwoods, and there were 2.8 · 10³ ha planted with agricultural crops (cocoa, oil palm, coffee, etc.).

Permanent sample plots (PSPs) have been established in every 250-ha block. A pair of 0.5-ha plots is measured annually: diameter, breast height (DBH) for all trees and the top height of the largest-diameter 100 trees ha are recorded. A total 7.3 · 10³ ha of *Albizia falcataria* have been planted, but only relatively small areas of *Acacia mangium*, on poor sites, and *Leucaena leucocephala* have been planted.

A. falcataria

Data on *A. falcataria* are available from 10 PSPs about 7 years old, and inventory figures

Table 1. Volume growth (MAI) of three *A. falcataria* plantations

Height class[a] (m)	PSPs	Age (months) 36 (m^3 ha^{-1})	48 (m^3 ha)	60 (m^3 ha)	72 (m^3 ha)	81 (m^3 ha)
5.5	3	28	41	51	48	49
5.0	4	16	28	37	41	42
4.5	3	15	25	32	36	35

[a] MAI of 100 trees with the largest diameters at 60 months.
[b] MAI = volume to 7 cm diameter.

Table 2. Proportion and volume of *A. falcataria* height classes per hectare at 5 years (to 7 cm diameter).

Height class (m)	Proportion of crop (%)	MAI (m^3 ha)	Actual volume (m^3 ha)
6.5	6	65	2.7
6.0	11	60	5.0
5.5	22	50	9.9
5.0	31	42	14.0
4.5	27	34	12.1
3.5	3	21	1.3

Table 3. *A. mangium* growth data.

Age (months)	Density (trees ha)	Mean DBH (cm)	Mean height of 100 'largest-diameter trees (m)	Volume (m^3 ha)
28	1330	9.7	11.4	—
34	1040	11.6	13.5	—
42	1020	13.3	17.2	—
48	990	14.4	19.0	110
60	880	16.0	21.6	145

exist for three 5-year-old plantations (Table 1). The stocking of the plantations varies between 600 and 900 stems ha, and the effect of this spacing has yet to be ascertained. Mean annual increment (MAI) is culminating between 60 and 80 months and will range from 30 m^3 ha to 50 m^3 ha, depending on the site.

Inventories of the 1975–77 plantations cover a range of height classes (Table 2), with MAI volume being 45 m^3 ha at 5 years.

An estimated 30% of the crop will be sawlog class (25 cm DBH) at 8 years — the economic rotation age in unthinned stands. The time could be reduced by early thinning.

A. mangium

The growth data (Table 3) for *A. mangium* have been taken from two PSPs. As individual tree measurements include some forked trees, the number of stems hectare is greater than for *A. falcataria*, although the original spacing was the same. Sabah Softwoods is anticipating a mean annual increment in volume of 30 m^3 ha.

Table 4. *L. leucocephala* growth data.

Age (months)	Mean DBH (cm)	Mean height for 100 largest diameter trees (m)
15	4.2	5.8
24	5.5	7.1
36	5.7	8.6

L. leucocephala

K28 is the leucaena cultivar being tested by Sabah Softwoods, but the soils are pH 4.5–5.0 — too acidic to support good growth. Liming has been considered by the company but does not appear to be an economic proposition. Growth data have been collected for 3 years (Table 4).

Discussion Summary

Leucaena wood in the tropics is primarily used for fuel. Firewood is expensive — for example, as much as US$ 30–60 t in parts of India — and poor farmers could supplement their incomes considerably by selling fuelwood from leucaena. In the Philippines, the government is offering to buy leucaena to fuel its dendrothermal energy program, requiring about 100 t/day for each 5-MW generator. Farmers who grow the crop for the program will be paid US$ 7–10 t of dry wood.

Another important potential use for leucaena wood is in the manufacture of pulp. Batch-size industrial tests in Taiwan have demonstrated the excellent pulp qualities of the species, and, recently, more than $1 \cdot 10^3$ t of leucaena wood (stems >3 cm in diameter) were tested at the Chung Hwa Pulp Corporation and found to be better than traditional tropical hardwoods. The company operates a credit program involving farmers and has already planted about $9.0 \cdot 10^3$ ha of leucaena.

Minor products of leucaena showing promise are poles, sawlogs, and parquet flooring. Poles of 4-year-old eucalyptus in India cost as much as US$ 25 each and could easily be replaced by leucaena. Similarly, leucaena could be substituted in parquet flooring in the Philippines and Thailand. Leucaena lumber has been found to dry well after being cut, although its widespread use is limited because of its relatively small diameter.

Most wood plantations have been established from bagged seedlings. Increasingly, however, bare-root transplanting and direct seeding are being utilized with surprisingly good results. In Taiwan, bare-root transplants were shown to be half the cost of potted seedlings. When seedlings must be transported over long distances, the bare roots can be packed in a mud slurry containing rhizobia. In the Philippines, direct seeding has been shown to be a cheap, efficient method of establishing leucaena on grasslands, provided weeds are controlled until the plant can compete successfully. In fact, intensive weeding and good site selection are the two key criteria for good growth, but fertilization for wood production should not be overlooked.

Growth and wood yield are a function of site quality, age, spacing, and management, all of which have to be integrated into yield models for production purposes. An attempt to develop yield models has been undertaken in the Philippines, but it relies primarily on volume and spacing variables rather than preplant environment. Models based on "site index," i.e., relative height of a plantation at a standard age as a reflection of site quality, may be too rigid because they do not accommodate soil amelioration and maintenance, which positively affect leucaena yield as well as site index.

The most commonly used formula for the calculation of volume is that of Kanazawa (volume = 0.5 height · DBH^2). Although this formula is convenient, especially in comparisons of volumes at different sites, it is based on only one location and tends to overestimate the volumes of large diameter trees. A form factor (ratio of tree volume to volume of a cylinder with the same diameter and length) has been calculated as 0.6 (average value) in Taiwan and Hawaii, and a range of 0.55–0.67 was found for 2000 trees harvested in the Philippines.

There is little reliable information on coppice management and physiology of leucaena. On bad sites with wide spacing, coppice regrowth can be profuse and slow. On good sites, regrowth is fast and self-pruning, with 1–2 stems emerging per stump at the end of 1 year.

Seed production is a growing industry worldwide, with good-quality seed being available at low prices in several countries. However, recently, mixed, inferior seed has been placed on the market, and buyers should check seed sources by corresponding with experts. Seed production could be enhanced if one reputable institution in each nation were given the responsibility to produce foundation seed and distribute it to local seed producers for increase and sale. Land requirements and costs would be minimal, and the benefits from the use of genetically reliable seed would be great.

Several pests and diseases have emerged in the last few years. The most serious is a fungal gummosis, the first sign of which is a bark

canker from the soil. The canker spreads 1–2 m up the stem. Some varieties are extremely susceptible to the disease and die if infected. Most varieties recover, but their weakened stems are subject to wind damage. The responsible agent is probably *Phytophthora* sp. (possibly *P. dreschleri*), as identified in Hawaii and Taiwan, although, in India, the causal agent was identified as *Fusarium* sp. *Camptomeris leucaenaea*, also a fungus, attacks leaves and can cause defoliation. The disease is limited to Central America, and resistance does exist. Scale insects attack trunks of leucaena trees in Taiwan and in times of drought cause death. Another pest, boring insects, attacks roundwood soon after harvest in the tropics and precludes long periods of storage or, even, drying.

Soil
Restoration

The bushy common leucaena is used in Sikka, Indonesia, for terraces to control erosion. The dense, interwoven vegetation stops runoff more effectively than does the giant type

A Farmer's Practical Guide for Giant Leucaena (Lamtoro Gung)

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The adaptability and multiple uses of lamtoro gung (giant varieties of Leucaena leucocephala) give it a comparative advantage over other species in large areas of Indonesia where the dry season lasts longer than 3 months. For this reason, the Provincial Development Program is designing and testing cropping systems based on leucaena. Two August 1982 meetings — Lamtoro Gung Workshop and the National Lamtoro Seminar I — provided a forum for exchange of research results and field information on the legume, and participants emphasized the farmers' need for practical information to guide the field implementation of projects including lamtoro gung. A table of crop-management recommendations was drawn up. This table, accompanied by written explanations, provides extension workers and progressive farmers with technical information that can be easily adapted to local conditions. The recommendations for planting and cultural practices are based on the intended use — main purpose — of the crop. The idea is that farmers will choose one of six possible main purposes and follow the procedures recommended for that purpose. Although the recommendations are designed to maximize the primary product, they also allow for secondary products.

L'adaptabilité et les usages multiples auxquels elles se prêtent confèrent aux variétés géantes de Leucaena leucocephala *(lamtoro gung) un avantage sur d'autres espèces dans de vastes régions de l'Indonésie où la saison sèche dure plus de 3 mois. C'est pourquoi le Programme de développement provincial étudie et fait l'essai de systèmes culturaux à base de* Leucaena. *Deux réunions, en août 1982 (Colloque sur le lamtoro gung et Séminaire national lamtoro) ont servi de tribune pour la publication des résultats obtenus et pour un échange d'informations sur cet arbre de la famille des légumineuses. Les participants ont insisté sur la nécessité de fournir aux cultivateurs des directives pratiques pour la réalisation de divers projets incluant le lamtoro gung. Une table de recommandations a été rédigée pour les pratiques à suivre, accompagnée d'explications écrites destinées aux responsables de la vulgarisation et aux exploitants de fermes modèles, et que ceux-ci pourront adapter aisément aux situations locales. Les recommandations sur la plantation et les pratiques culturales ont été conçues en fonction de l'utilisation prévue (l'objectif principal) de la récolte. Les cultivateurs se voient offrir un choix de six objectifs principaux éventuels avec, pour chacun d'eux, les méthodes recommandées pour les réaliser. Bien que s'attachant surtout à maximaliser le produit primaire, ces recommandations tiennent compte également des produits secondaires.*

La adaptabilidad y los multiples usos del lamtoro gung (variedades gigantes de Leucaena leucocephala*) le dan una ventaja comparativa sobre otras especies en grandes areas de Indonesia donde la estacion seca se prolonga por mas de 3 meses. Por esta razon, el programa de desarrollo provincial se ocupa en desenar y probar sistemas de cultivo basados en leucaena. Dos reuniones sobre el lamtoro celebradas en agosto de 1982 proveyeron un foro para el intercambio de resultados investigativos e informacion de campo sobre la leguminosa, y los participantes hicieron énfasis en la necesidad de los agricultores de una informacion practica que guiara la implantacion en el campo de los proyectos que incluyen el lamtoro gung. Se elaboro un cuadro de recomendaciones sobre el manejo del cultivo. Este cuadro, acompanado por explicaciones escritas, proporciona a los extensionistas y agricultores una informacion tecnica que pueden facilmente adaptar a las condiciones locales. Las recomendaciones para las practicas culturales y de plantio se basan en el uso pretendido —proposito principal del cultivo. La idea es que los agricultores escojan uno de seis posibles propositos principales y sigan los procedimientos recomendados para ese. Aunque las recomendaciones se diseñan para maximizar el producto primario tambien sirven para productos secundarios.*

Lamtoro gung (leucaena varieties with K designations as well as Peru and Cunningham) has generated widespread interest in Indonesia. Many government and nongovernment institutions are implementing research and field activities incorporating the legume, and two important national meetings on the subject were held in 1982. The first was the Lamtoro Gung Workshop, 19–21 August, sponsored by the Ministry of Home Affairs and jointly opened by three ministers (Home Af-

[1] The views expressed in this paper are mine and not necessarily those of AID–Indonesia.

fairs, Environment, and Agriculture). This workshop focused on five provinces — East Nusa Tenggara, West Nusa Tenggara, East Java, Central Java, and the Special Province of Jogyakarta — in which leucaena projects have been launched. The farming practices in these areas are similar, based on rainfed cultivation of small parcels of poor, hilly soils in climates with a dry season that lasts longer than 3 months. Leucaena provided farmers the opportunity to generate income while reducing erosion and improving soil fertility. The results of the workshop were sent to all national, provincial, and district administrators and heads of technical agencies.

The second was the National Lamtoro Seminar I, 23–25 August, which was hosted by the Agency for Research and Application of Technology (BPPT). The organizers of this meeting received 52 abstracts, from researchers and field implementors, of which 41 were selected for presentation. Thus, individuals from all over Indonesia were able to share their research and field experience, and the information presented is not only of general importance for Indonesia but also of international interest. It covers leucaena's uses as fodder for ruminant livestock, hedgerows for reducing erosion, and fermented seed cake (*tempe* in Indonesia) for food. It also features leucaena varieties suitable at various altitudes from sea level to 1500 m and on acid soils (pH 5.5).

Both national meetings demonstrated that many people and institutions in diverse locations of Indonesia are researching and implementing projects that include leucaena for the purpose of direct use by farmers. Efforts include the development of leucaena-based cropping systems by the Provincial Development Program (PDP); the promotion of hedgerows to reduce erosion in Sikka District; energy research and leaf-production field trials assisted by BPPT; and varietal trials at various altitudes and on acid soils by the Ministry of Agriculture in North Sumatra Province.

PDP's efforts to develop cropping systems for small farmers in East Nusa Tenggara (NTT) Province deserve special mention, especially the work of Roberto Monserrat, PDP agricultural adviser who has cooperated with the Central Research and Development Institute of Food Crops of the Agency for Agricultural Research and Development (Department of Agriculture) and various NTT provincial and local administrative and technical services. During the past 3 years, the focus has been field-station plots and farmers' fields. During

East Nusa Tenggara during the dry season, which will continue another 2 months or more.

1982–83, demonstration plots will be established in 65 villages.

The two national meetings emphasized that leucaena is attractive to farmers because of its ability to generate income and reduce erosion while allowing them to produce food crops. Although this sounds relatively straightforward, the farmers do need to learn new cultural practices for the crop. For example, one farmer who planted leucaena, eventually ripped out 4-m tall trees from his fence row because his food crop yielded comparatively less near the trees than in the middle of the field. He believed that the roots of the leucaena were the problem. Neither the farmer nor the extension worker promoting the use of leucaena realized that the shade, not the roots of the trees, was the problem. Instead of destroying the trees, the farmer needed to coppice them for leaf production at the beginning of the food-crop planting season. He needed to be made aware that he could produce green manure and forage from the trees while producing a healthy food crop. This example is typical of what happens when not enough basic information is available to farmers and extension workers. It prompted the preparation of a list of management recommendations (Table 1), which were attached to the final report of the Lamtoro Gung Workshop.

Explanations of the Recommendations

The Lamtoro Gung Workshop was based on reports of field experiences that were primarily aimed at:

- Increasing farmers' incomes on small areas of land, while
- Improving the environment through erosion control and soil amendment.

These were the guiding principles for the management recommendations as well. Possible large-scale applications (energy plantations, silvipasture systems, and monoculture reforestation) were not addressed.

The recommendations were based on the intended use — main purpose — of the crop. Six possible main purposes were drawn up, and planting procedures and cultural practices that would maximize each one were listed. Farmers can choose the purpose that best suits their needs and follow the practices recommended for that purpose. The technical information has been synthesized from research trials and field-implementation reports from Indonesia as well as other countries. Nevertheless, the recommendations must be adapted to local conditions.

Before continuing with more detailed explanations, I think some general comments are needed. The term, lamtoro gung, is used for varieties having the K designators such as K6 (Peru), K8, K28, K67, etc. Also included is one variety, Cunningham, released by the Commonwealth Scientific and Industrial Research Organization (CSIRO), Townsville, Australia. Uses for the varieties most common in Indonesia are:

- K8, K28, and K67: firewood and poles. These varieties have fewer and higher branches (except when coppiced) than other varieties, and coppicing causes a substantial increase in branching and leaf production so that K8 and K28 forage yield is similar to Peru and Cunningham.
- Peru and Cunningham: leaf production for animal feed and green manure. These varieties, without coppicing, have more and lower branches than the other K varieties.

Some general points need to be emphasized in the use of the management recommendations (Table 1):

- One main purpose for each location must be selected before planting is done;
- Cultural practices directly relate to the main purpose;
- The planting system depends also on the main purpose and on the cultural practices;
- Leaves and young stems can constitute 100% of the diet of ruminant animals to be fattened for slaughter. Most efficient weight gain is obtained, however, with 40% lamtoro gung leaves and 60% roughage such as grass, straw, or crop wastes;
- Leaves and young stems can make up 30% of the diet of ruminant breeding stock with no ill effects;
- Leaves and young stems can be 5–10% of the diet of chickens, pigs, and rabbits with no ill effects;
- Plant growth is less vigorous at elevations above 500 m, in soils below pH 6, in waterlogged soils, and in saline soils;
- Germination rates can be improved by scarification of the seeds;
- Plant growth is enhanced by atmospheric nitrogen fixation, which is assisted by inoculation of seeds with soil taken from

Table 1. Management recommendations for smallholders growing leucaena in Indonesia

	Planting			Cultural practices			
	Spacing	Material	Population (seed required)	0–12 months*	Older than 12 months	Primary product*	Secondary products*
Main purpose: Trees for seed							
Slope 0–5%	3 m × 3 m	Seeds, seedlings	1111 /ha (0.25 kg/ha)		Continue to harvest seed until tree becomes too tall or rainy season begins	Seeds: *0–12 months* 0.25–0.5 kg/tree, *>12 months* 0.75–1.0 kg/tree/year	Firewood plus leaves for animal feed when trees are cut
Slope 5–50%	2 m × 5 m	Seeds, seedlings	1000 /ha (0.22 kg/ha)				
Main purpose: Conservation, reducing erosion							
Slope 0–15%	Double rows: 25 cm × 5 m	Seeds	16000 /ha (3.6 kg/ha)	A food crop that does not excessively shade the leucaena is planted between the double rows	Replace dead plants, coppice for secondary product if diameter is >3 cm	Reduced erosion	Leaves (5–10 t/ha by fresh weight) for green manure (growing season) or animal feed
Slope >15%	Double rows: 25 cm × 2 m 10 cm × 2 m	Seeds	40000 /ha (8.9 kg/ha) 100000 /ha (22.25 kg/ha)	A food crop that does not excessively shade the leucaena is planted between the double rows	Replace dead plants, coppice for secondary product if diameter is 3 cm	Reduced erosion	Leaves (10–20 t/ha by fresh weight)
Terrace	Raised bed: 0.5 cm × 10 m	Seeds, seedlings, stumps	2000 /ha (0.4 kg/ha)	Interplanted food crop	Replace dead plants, coppice induce leaf shed if diameter is >3 cm	Not yet studied	Leaves (no measurement of production yet)
	Bench: 1 m × 2 m	Seeds, seedlings, stumps	5000 /ha (1.0 kg/ha)	Interplanted food crop	Replace dead plants, coppice induce leaf shed if diameter is >3 cm	Not yet studied	Leaves (no measurement of production yet)
Home garden	25 cm in the row	Seeds, seedlings, stumps	400/100 m (90 g/100 m)	Interplanted food crop	Replace dead plants, coppice for secondary product if diameter is >3 cm	Reduced erosion, leaves	Leaves, firewood, food (no measurement of production yet)
	Individual 2 m × 3 m	Seeds, seedlings, stumps	17/100 m² (3.6 g/100 m²)	Interplanted food crop	Replace dead plants, coppice induce leaf shed for green manure if diameter is 3 cm	Reduced erosion, leaves	Leaves, firewood, food (no measurement of production yet)

Main purpose: Leaves for animal feed							
Fence	0.75 – 1 m	Seeds, seedlings, stumps	100 – 133 100 m (22 – 30 g 100 m)	Coppice, when trunk is 3 cm in diameter, 0.7 – 1 m above ground	Coppice every 3 months during the rainy season, every 4 months during the dry season	Leaves from two coppiced trees/day for each head of cattle being fattened	Firewood, green manure
Field	1 m × 1 m	Seeds, seedlings, stumps	10000/ha (2.2 kg/ha)	Coppice when trunk is 3 cm in diameter, 7.0 – 1 m above ground	Coppice every 3 months during the rainy season, every 4 months during the dry season	Feed for 2 – 3 head of cattle/ha	Firewood, green manure
Main purpose: Firewood							
Field	1 m × 2 m	Seeds, seedlings, stumps	5000/ha (1.1 kg/ha)	Do not cut	Cut the tree 30 cm above ground when trunk diameter is 7 cm, leave only three branches of regrowth	Firewood (20 m³/ha after 2 years)	Leaves (when tree is cut)
Fence	1 – 1.5 m	Seeds, seedlings, stumps	67 – 100/100 m (15 – 22 g/100 m)	Do not cut	Cut the tree 30 cm above ground when trunk diameter is 7 cm	Firewood (20 m³/ha after 2 years)	Leaves (when tree is cut)
Community	2 m × 3 m	Seeds, seedlings, stumps	1666/ha (0.37 kg/ha)	Do not cut	Cut the tree 30 cm above ground when trunk diameter is 7 cm	Firewood (20 m³/ha after 2 years)	Leaves (when tree is cut)
Main purpose: Trees for shade							
	Double rows: 0.25 m × 2.5 – 6 m	Seeds	13333 – 32000/ha (3.0 – 7.1 kg/ha)	Do not cut	Depending on the shade required, coppice first time when the trunk is 3 cm in diameter	Shade for other cash crops (coffee, cocoa)	Reduced erosion, green manure, animal feed
Main purpose: Green manure							
Slope 0 – 15%	Double rows: 0.25 m × 5 m	Seeds	16000/ha (3.6 kg/ha)	Do not cut	Coppice when trunk is 3 cm in diameter, 0.7 – 1 m above ground	Leaves (5 – 10 t/ha by fresh weight)	Leaves for animal feed once during the season

[a] For all the main purposes, the leucaena requires weed control and protection from fire and animals in the 1st year. Only the additional measures have been listed in this column.

[b] Both primary and secondary products are for trees older than 12 months unless otherwise indicated.

beneath vigorously growing lamtoro trees or with commercial inoculum, when available, immediately before planting so that the sun does not kill the live bacteria;

- Plants can be frequently coppiced but will have a longer, more productive, life if stems are 3 cm (the width of a thumb) in diameter before the first cutting, cut at the height of 0.3 – 1 m, and allowed to regrow for 3 months in the rainy season and 4 months in the dry season.

Definitions of Categories in the Management Recommendations

Main purpose

Lamtoro gung may be used as a permanent or temporary component of cropping systems. It may be interplanted in hedgerows, alley cropped, planted as a border, or grown as an individual plant with other crops. It stabilizes and improves soil fertility. It has potential to produce a variety of products, but it can serve only one main purpose at a time. For example, the most leaves are produced when the tree is frequently coppiced and, hence, does not continuously produce seeds. If both seeds and leaves are desired from one plant, the production of both will be lower than it would be when only one product (i.e., seeds or leaves) is regularly harvested.

Planting

Each main purpose has a recommended spacing for effective production of the desired product, be it seeds, leaves, firewood, or erosion control. However, variations in soil and climate conditions at a particular site require slight adjustments for maximal productivity. Choice of planting method is dependent on factors such as seasonal availability of labour, germination percentage, cost of seeds, etc. The three methods (direct seeding, transplanting of seedlings, and stump planting) have differing requirements.

The choice of a method for demonstration plots must be consistent with local farmer capabilities. For example, the selection of the main purpose "conservation, reducing erosion" means that tens of thousands of plants per hectare will be planted. Because of the large number of plants, the farmer will probably choose direct seeding, especially if he or she already has seeds. The cost considerations and ease of implementation offset the lower germination rates to be expected with direct seeding. Farmers can consult local extension workers for assistance.

The density of plants is calculated from the spacing at planting and the assumption that 100% of the seeds will grow. The required amount of seeds (~15 000 seeds/kg) is based on the recommended plant density for each main purpose and the estimated survival rate from germination to 6 months. The percentage used for calculation for each planting method is: seed (direct) 30%, stump 50%, and seedling 60%.

Cultural practices

Lamtoro gung appears to grow very slowly the first 3 months after germination, as most of the plant's energy is spent in putting down a strong taproot. During the 1st year's growth, including the dry season, lamtoro gung must be protected primarily from the shade of faster-growing plants (weeds), fire, and grazing livestock. After the 1st year, cultural practices and expected products relate to the chosen main purpose. For example, if the main purpose is for animal feed, the plants should be coppiced every 3 months in the rainy season and every 4 months in the dry season. Another example: if the main purpose is green manure, lamtoro gung 3 cm in diameter should be coppiced 1 week before the food crop is planted and the cuttings immediately incorporated into the soil for maximum nutrient benefit.

Although application of phosphate fertilizer will enhance establishment, it is not recommended because output is to be maximized with minimum inputs and low risks to farmers living in a subsistence or limited cash economy.

Primary and secondary products

The primary product is the one that fulfills the main purpose and for which the planting system and cultural practices have been designed. The secondary products are those that are possible with the planting system and cultural practices required for the yield of the primary product.

Achieving the Main Purpose

Trees for seed

Seed trees should be allowed to grow until either the seed pods become too high to harvest easily or the third rainy season begins, whichever comes first. Then they should be cut to 1.5 m high, with only three sprouts (spaced evenly around the trunk) being allowed to grow back.

Seeds should not be harvested in the rainy season because of increased prevalence of pathogens and insects. Regrowth will be rapid in the rainy season, and seeds will be ready to be harvested at the beginning of the succeeding dry season. The fruiting season is usually long and continuous. Pods should be harvested when mature (yellow) and not overly mature (dark brown) because, with age, the seed coats harden and insect - disease damage increases. Mornings and evenings are preferred times of the day for harvesting so that the seeds lost through pods' shattering are minimized.

Seeds for storage should be immediately separated from the pods, cleaned, and sun-dried for 3 days. The seeds should be dry when stored, and airtight containers should be used for storage. Farmers commonly dust stored seeds with wood ash (1 part sifted ash to 2 - 4 parts seeds) to deter insects and pathogens.

Conservation, reducing erosion

To reduce erosion and increase soil fertility, one must save the topsoil. Planting leucaena is an effective way of doing this, and it has advantages for secondary products. For example, coppicing the plants and applying the leaves to the soil can provide nutrients for interplanted food crops. The four recommended systems are: for slopes 0 - 15% not terraced; for slopes greater than 15% not terraced; for existing terraces that need improvement; and for home gardens. In all these systems, the cultural practices are similar. That is, during the 1st year, the lamtoro gung should be:

- Planted on raised ridges or beds, especially in the first three systems;
- Planted just before the rainy season; and
- Protected from too much shade, weeds, fire, and animals.

After the leucaena becomes established, the timing, frequency, and height of coppicing depend on the types and ages of the crops to be interplanted with it. For example, if there are food crops, the important general principle is that lamtoro gung must not excessively shade the interplanted food crops.

The primary product is erosion control, but the secondary products deserve special attention, and the timing of cultural practices is important. If food crops are to be interplanted with leucaena, the steps would be:

- 1 week before planting the food crop, coppice the lamtoro gung 0.3 - 1 m above ground so that lamtoro gung does not shade out the food crop;
- Incorporate the leaves immediately into the soil because the nutrient contribution of the cuttings as green manure is greater than when incorporated later;
- 1 month after the food crop is planted, coppice the lamtoro gung again and apply on the soil surface as green manure;
- Each time lamtoro gung is coppiced, cut a little higher on the plant so that more branching takes place and, therefore, more production of leaves; and
- During the dry season, when crops are not interplanted, coppice only one time for use as animal feed.

Green manure can be obtained by the shedding method, which reduces labour considerably. In this method, one girdles or removes a 20-cm wide strip of bark on the trunk 1.5 m above ground. Within 1 month, the leaves dry and fall. Shoots grow back from the portion of the trunk below the girdled area. Only three shoots should be allowed to grow.

These are some general principles and cultural practices for the four conservation, reducing-erosion systems. Some of the differences among the systems are:

- For slopes of 0 - 15% not terraced: seeds and seedlings are planted along the contour of the hill in double rows, with 40 cm between the two rows and 10 cm between plants in the row. The distance between two double rows is 5 m.
- For slopes greater than 15% not terraced: seeds or seedlings are planted along the contour of the hill in double rows, with 40 cm between the two rows and 5 cm between plants in the row. The distance between two double rows is 2 m.
- For existing terraces: when landholdings are very small, lamtoro gung is planted on the terrace not only to provide green manure for interplanted crops and animal feed in the dry season but also to allow the taproots to loosen the soil, improve water infiltration, and reduce runoff.
- For home gardens: leucaena may be an individual plant, intercropped or used as a fence in humid and drought-prone areas. The advantage in dry areas is that the taproots penetrate the soil to find water and bring plant nutrients closer to the surface where other plants can use them.

Leaves for animal feed

There are two suggested planting systems to be used with the cut-and-carry harvesting system for penned animals. These are:

- Fence: lamtoro gung is planted as a living fence. The principle is to make the land more productive, but it does not restrict access of animals;
- Field: lamtoro gung is planted in a field to produce animal feed as the primary product.

For fattening of ruminant animals, the leaves are most effective if they constitute about 40% of the total ration. Research results obtained by the government of Indonesia, at the Livestock Research Centre, Ciawi, West Java, and field experiences from East Nusa Tenggara show that leaves have no toxic effect even when fed as 100% of the ration for fattening ruminants. This finding has particular implications for the dry season when other feeds are unavailable.

Firewood

There are three suggested planting systems for a primary product of firewood:

- Field: lamtoro is planted in a field to produce firewood as the primary product.
- Fence: lamtoro is planted as a fence around the home garden, along the road, etc.
- Community forest: lamtoro is planted on selected community lands reserved for the planting of firewood as the primary product.

All three of the above systems will produce firewood as the primary product as well as produce leaves for animal feed or green manure as a secondary product at the time the trees are cut.

Trees for shade

When the main purpose is to provide shade on slopes 0–50% or steeper, seeds or seedlings are planted along the contour of the hill in double rows, 40 cm between the rows and 25 cm between the plants in the row. The trees will be thinned to suit the shade requirements of the interplanted crop. The distance between two double rows is from 2.5 m to 6 m, depending on the planting distance for the crops to be shaded and the steepness of the slope. Only tree crops should be grown on the steep slopes.

Green manure

The recommended method to produce green manure as the primary product is to plant lamtoro gung in double rows, with the distance between the rows 40 cm and 25 cm between plants in the row. There are two green manuring methods: coppicing and the induction of shedding.

Research in the Philippines has demonstrated that:

- The effect of lamtoro gung as green manure for corn is the same as that from NPK fertilizer applied at the rate of 90-40-40 kg ha; and
- Rainfed upland rice (IR36 variety) when provided with lamtoro gung as green manure yielded as well as can be expected from NPK-fertilized plots (80-30-30 kg ha).

Conclusions

The management recommendations evolved because of field-implementation needs and the unavailability of practical materials for field use. The scope and the organization of the recommendations, according to main purpose, reflects the farmers' situation in the areas of the five provinces where lamtoro gung is being actively promoted. Thousands of hectares of land supporting tens of thousands of people were planted to lamtoro gung even without technical guides. It is hoped that the main purposes of the management recommendations will be further developed for farmers' use.

I recognize that the recommendations are only a first attempt to organize information into a format for field use, and I solicit specific constructive suggestions.

Leucaena for Erosion Control and Green Manure in Sikka

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Sikka district, on the island of Flores, Indonesia, is small, densely populated, dry, and eroded. Since 1973, its people have successfully planted lamtoro (Leucaena leucocephala) for erosion control and green manure. Lamtoro biasa is a local term used for the Hawaiian type leucaena. The local people plant this type to create hedgerows for terraces to control erosion. The Hawaiian giants are planted in the flat areas of bench terraces. More than 2.0 × 10^4 ha of hilly lands are already terraced, and more than 2 million Hawaiian giants have been planted. On these terraced lands, perennial crops, such as cocoa, cloves, pepper, etc., are being grown, and BIMAS, the national food crops intensification program, is providing improved varieties of upland rice and corn to farmers who plant leucaena. The successful results so far reflect leucaena's ability to meet the farmers' needs and to become a Tanaman Rakyat *(people's plant), a* Tanaman Pelopor *(pioneer plant), and a* Tanaman Perdagangan *(cash crop).*

Le district de Sikka, dans l'île de Florès, est peu étendu mais fortement peuplé et les terres sont arides et érodées. Depuis 1973, ses habitants ont planté avec succès le lamtoro (Leucaena leucocephala) pour combattre l'érosion et comme engrais vert. Lamtoro biasa est un terme local désignant le Leucaena de type hawaïen. Les indigènes s'en servent comme haies pour les terrasses aménagées contre l'érosion. Les géants hawaïens sont plantés dans les parties planes des terrasses en gradin. Plus de 2,0 × 10^4 ha de collines sont déjà aménagés en terrasses et plus de 2 millions de géants hawaïens y ont été plantés. Ces terrains portent des récoltes permanentes de cacao, de girofliers, piments, etc. et BIMAS, le programme national d'intensification des cultures vivrières, fournit des variétés améliorées de riz et de maïs pour terres hautes aux cultivateurs qui plantent des Leucaena. *Les succès obtenus jusqu'ici témoignent des possibilités qu'offre* Leucaena *de répondre aux besoins des cultivateurs, en devenant pour eux une* Tanaman Rakyat *(plante du peuple), une* Tanaman Pelopor *(plante pionnière) et une* Tanaman Perdagangan *(culture de rapport).*

El distrito de Sikka, en la isla de Flores, Indonesia, es pequeño, densamente poblado, seco y erosionado. Desde 1973 su gente ha sembrado con éxito lamtoro (Leucaena leucocephala) para controlar la erosion y producir abono verde. El lamtoro biasa es un término que designa la leucaena de tipo hawaiano. La poblacion local siembra ese tipo en hileras para formar terrazas contra la erosion. Las gigantescas plantas hawaianas son sembradas en las areas planas de las terrazas. Mas de 2.0 × 10^4 ha de colinas están ya en terrazas, y mas de 2 millones de estos arboles han sido sembrados. En estas terrazas se siembran cultivos perennes como el cacao, el clavo, la pimienta, etc., y el BIMAS, programa nacional de intensificacion de cultivos alimenticios, proporciona variedades mejoradas de arroz alto y maiz a los agricultores que siembran leucaena. Los resultados exitosos hasta ahora reflejan la capacidad de la leucaena para hacer frente a las necesidades de los agricultores y convertirse en una Tanaman Rakyat *(planta popular), una* Tanaman Pelopor *(planta pionera) y una* Tanaman Perdangangan *(cultivo de efectivo).*

Sikka district on the island of Flores, is one of the smallest (1670 km^2), most densely populated (120 people km^2), and driest (954 mm rainfall on the north coast, 1192 mm on the south coast, and 1500 mm in the mountains) districts in the province of Nusa Tenggara Timur in the southeastern part of Indonesia. Metzner (1976: 103–105) described some important details about this district:

- A stratum of volcanic ash and tuff several hundred meters thick covers this area. Water courses have cut deeply into this volcanic rubble, so that only 20 per cent of the area has a slope of less than 10 per cent. Flat surfaces are therefore rare.
- Irrespective of the regional differences in annual rainfall distribution, all parts of Sikka suffer from acute water shortage during the dry season which seriously affects cultivation since no technical irrigation is possible. Only those plants with deep roots can survive on the sandy soil during the dry season, in spite of the fact that some of the hill soils are quite fertile.

Agriculture production is thus set quite narrow limits by this long dry season and by the rugged terrain. Only 20 per cent of Sikka's total area is used for cultivation. Dry farming predominates with crop rotation in a short cycle of three to four years of cultivation with an equal period of fallow, even on fields with more than 30 per cent of slope.

The area has been described as including 14 620 ha good for upland rice, secondary crops, and perennial crops; 46 810 ha highly restricted for upland rice and secondary crops, good for perennial and forage crops; and 79 720 ha of land that is not good for agriculture: very thin upper horizon and very stony, only good for forestry and certain trees. Thus, erosion control (Ten Dam 1950) is essential. Bench terraces were introduced in 1966, but, because of the hard work in setting them up and the lack of immediate payoffs, the population was reluctant to adopt them.

Starting in 1971, planting trials with the Hawaiian type of leucaena (lamtoro biasa) were successful in controlling erosion and led to planting on a larger scale in 1973.

In 1978, the Hawaiian giants, lamtoro gung (agung = the great) as they are named in Indonesia, were introduced. Now, more than 2 100 ha of hills are terraced with lamtoro biasa and more than 2 million lamtoro gung trees have been planted in Sikka.

BIMAS, the national food crops intensification program, operated by the District Agriculture Service, was introduced in Sikka in 1974. This program makes available, on a credit basis, improved varieties of upland rice and corn as well as fertilizers and insecticides. A local regulation stipulated that only farmers who planted leucaena on their land could take advantage of the national program. Local authorities reasoned that the leucaena would halt runoff and ensure that the fertilizer would not be washed away along with the precious topsoils.

Perennial crops such as cocoa, cloves, pepper, etc., were planted on the terraced beds and worked not only as a component for the successful cultivation of leucaena but also as an integral part of the permanent agriculture based on leucaena (Prussner 1981).

A new development has since taken place. Bench terraces, the construction of which was practically abandoned when indirect terraces were created by leucaena hedgerows, are again being constructed. Now, the bench terraces are supplemented with rows of Hawaiian-type leucaena grown along the edge of the terraces and Hawaiian giants planted in the flat areas. This arrangement has proved very effective in erosion control. The flat surface of the bench terraces slows the flow of water, the hedgerows arrest the overflow, and the Hawaiian giants with their deep taproots improve percolation through the hard layers.

An old poem describes well the concept:

> Uma puang naha nora tuang (forest must be on the upper side), uma enit di naha nora tuang (forest must also be on the lower side) uma lorang naha nora blepeng (blepengs must be in the centre).

The effectiveness of leucaena in reducing water runoff is determined by the layout and timeliness of planting, which must be done on the contour and just before the short rainy season (< 4 months long). The Hawaiian-type seeds are sown on raised beds, whereas the Hawaiian giants are grown first in plastic bags and then planted out.

The first step in creating hedgerows for erosion control is to establish the contour lines. For this purpose, a water level or an A frame is used. Then, the weeds have to be eliminated, and raised beds of 20 cm × 10 cm constructed. The next steps are to level the beds and form a shallow furrow with a stick; then the seeds can be sown in the furrow. Depending on the slope of the land, 70–100 kg seeds/ha will be planted 3–5 m apart, i.e., 1 kg seeds for a single row 25–30 m long.

Many have asked why so many seeds are used. The reasons are that:

- The seeds used at the beginning of the project to initiate leucaena were imported and exhibited poor germination.
- The aim is to obtain a solid network of vegetation, not individually grown stems.

No special seed treatment is practiced. Sowing is done in October, at the hottest time of the year, and the hard coats of the seeds have enough time to be cracked by the hot sun before the first rain, and they sprout easily. The early establishment reduces the possible negative effects of the heavy rains in January and February; however, to reduce risks to the young plants, farmers sometimes place bamboo, small trunks, or folded coconut leaves on the underside of the beds and secure them to the ground.

If the rainy season starts before planting has been done, then the beds have to be protected, covered with banana stems. As legumes such as Bei Fai (*Albizia chinensis*), Luma (*Sesbania grandiflora*), Buw (*Phaseolus radiatus*), Wuek (*Cayanus cayan*), Heo (*Psopocarpus tetragonolobus*), etc., are found and planted almost everywhere in Sikka, the leucaena seed

Simple terraces made from bamboo, small trunks, or folded coconut leaves laid and secured horizontally across the slopes.

is not inoculated with rhizobia. This system of sowing seeds on prepared beds gives better results than the traditional system practiced since the Dutch colonial times.

Many people also have asked why the Hawaiian giant seeds are not used for hedgerows. The reasons are that

- Seeds for the giants are in short supply, even though the variety is already growing in Sikka.
- Sikka's volcanic ash soil, which is highly vulnerable to erosion, seems to be best protected by a solid network of vegetation provided by bundles of small, tough Hawaiian type stems, and
- Pruning of the low Hawaiian type leucaena is now once every 5–6 weeks but would probably have to be more often with the giant types.

The periodic pruning of the hedgerows (at 75–80 cm) prevents them from becoming weeds — a development that made them unacceptable to farmers in the past. Pruning should be done only after the plants are more than a year old. In many cases, poor performance of hedgerows can be traced to too-early pruning. In burned-over areas, the regrowth of leucaena can be stimulated by pruning.

Although not many farmers in Sikka intentionally use the pruned leucaena leaves as green manure for their crops, most of them throw the leaves around the places they have just pruned and the effects are the same: the upperside of the terraces benefiting from the practice (Metzner 1978).

The presence of the evergreen leucaena hedgerows also improves the microclimate. Some farmers have recognized the changes and have begun cultivating crops such as peppers, cocoyams, etc.

In areas where upland rice, corn, and cassava are planted together, the cassava is left in the ground after the other two crops are harvested. The farmers have found that if they do not prune the hedgerows again until after the cassava is harvested, the increased shade improves the cassava root yields. The leucaena also seems to have a beneficial effect on growth and production of the fruits from the coconut trees.

The green manure that is provided by the pruning of leucaena is beneficial but not sufficient to maintain soil fertility. It is a good supplement to inorganic fertilizer available to farmers through the BIMAS program. The Hawaiian giants have to be coppiced or pruned when food crops are planted among them so they do not excessively shade the interplanted crops.

Bench terraces incorporate giant leucaena on the flat

The traditional practice of the farmers in the central and western parts of Sikka is to break the branches of young *A. chinensis* and *S. grandiflora* plants and leave them hanging on the trees. The leaves wither and fall gradually among the young upland rice and corn plants. This practice, thus, was adapted to the leucaena giants in a system of girdling the trunks. Before the planting of upland rice and corn, the trunks of the trees are girdled in a ring 20 cm wide 1.5 m above the ground. Within a couple of months, all the leaves fall. New sprouts emerge at the lower part of the girdled area of the trunks, but only two or three sprouts should be left to grow. In Tana Ai of the eastern part of Sikka where leucaena planting has been difficult and slash and burn cultivation is still practiced, this system is showing some promise of adoption. The leucaena leaves decay quickly, and there are no trunks or branches remaining on the fields to be burned. In the past, burning has been practiced not so much to obtain fertile ash as to eliminate the trunks, branches, and leaves left from land-clearing operations.

Another effect of leucaena that has impressed the farmers is the emergence of earthworms after the 1st year of leucaena establishment. Earthworms to these farmers, with their background as shifting cultivators, are identified with fertile soil.

Conclusion

The introduction of leucaena to the agricultural system of Sikka is a practical application in line with Dioscoro L. Umali's request: "Help us to build production systems that are not carbon copies of those in industrialized countries. Our need is for models that are simple, based on indigenous sources and techniques native to the soil." The successful results so far reflect leucaena's ability to meet the farmers' needs and to become:

- A *Tanaman Rakyat* (people's plant) because, with only the simple techniques and capabilities possessed by the farmers, it can be planted and managed to produce profitable yields.
- A *Tanaman Pelopor* (pioneer plant) that enhances conditions for the introduction of improved agriculture techniques by its ability to rehabilitate soil, control erosion, and improve the ecoclimate.
- A *Tanaman Perdagangan* (cash crop) because the sale of seeds of the Hawaiian giant has already provided good income, and fast-growing Hawaiian giants provide leaves and wood that can be used in animal feed and charcoal, both of which promise to become commodities with a profitable future.

Discussion Summary

Leucaena is increasingly being used as a green manure or nurse tree in agroforestry schemes and as a means of erosion control. For example, in Indonesia leucaena has been widely planted on the island of Flores for green manure and slope stabilization.

Seeds are densely sown (20 kg ha^{-1}) in prepared, contour bands about 10–15 m apart. The resulting plantations conserve soil and improve the hydrological efficiency of the land. No scarification is performed on seeds, nor is there any attempt to irrigate. Crops are planted in spaces between the rows. Some 2.0 × 10^{5} ha have been treated in this fashion.

In Java and in Malaysia, leucaena is often used as a nurse crop, particularly for teak. Several different planting regimens exist. In Malaysia, leucaena is planted in the same rows as the timber trees about 3 m apart. In Java, Perum Perhutani, the state forestry corporation, plants teak and leucaena in alternate rows, spacing the leucaena closely within rows. Usually, the leucaena is not thinned or cut and, thus far, has not excessively shaded the timber species.

Some caution is needed in the use of leucaena for erosion control. Planting solid stands of leucaena at high populations on steep slopes is not recommended because groundcover will usually be shaded out. The result is exacerbated erosion, as water flows freely down the slopes between the trees. Although an allelopathic mechanism has been proposed to explain mature leucaena's ability to suppress other plants and although mimosine has been shown to be allelopathic in vitro, shading is a more plausible explanation, as weeds thrive in stands with mature, but partially opened, canopies.

The state forestry corporation of Java, Indonesia, interplants teak with leucaena, the latter providing shade and nitrogen to the former — a more valuable timber species.

References

Aguilar, L. 1943. Calorific values of Philippine woods. Philippine Journal of Forestry, 6(2): 217–228.

Allen, E.K., and Allen, O.N. 1961. Scope of nodulation in the Leguminosae. In University of Toronto. Recent Advances in Botany, Vol. 1. 9th International Botany Congress, Toronto, Canada. University of Toronto Press. 585–588.

Allen, H.L., and Duzan, H.W. Jr. 1982. Nutritional management of loblolly stands: a status report of the North Carolina State Forest Fertilization Cooperative. Paper prepared for the International Union of Forestry Research Organizations Symposium on Forest Sites and Continuous Productivity, University of Washington, Seattle, USA, 23–28 August.

Allen, O.N., and Allen, E.K. 1981. Leguminosae, a source book of characteristics, uses, and nodulation. Madison, Wisconsin, USA: University of Wisconsin Press. 212 p.

Anonymous. 1980. Brian pastures. In Queensland Department of Primary Industries. Annual Report 1980. Brisbane, Australia: Queensland Department of Primary Industries. 18–29.

1981. Brian pastures. In Queensland Department of Primary Industries. Annual Report 1981. Brisbane, Australia: Queensland Department of Primary Industries. 9–34.

Anstiss, R.C. 1957. Investigation into the potential productivity of 'acacia' (*Leucaena glauca*) in Mauritius. Revue agricole et sucriere de l'Ile Maurice 36: 39–49.

Atwood, S.S., and Brewbaker, J.L. 1953. Incompatibility in autoploid white clover. Ithaca, New York, USA: Cornell University, Agriculture Experimental Station Memoir 319: 47 p.

Bamualim, A., Jones, R.J., and Murray, R.M. 1980. Nutritive value of tropical browse legumes in the dry season. Proceedings Australian Society of Animal Production, 13: 229–232.

1982. Effect of season on digestibility and chemical composition of some tropical browse plants. Proceedings Australian Society of Animal Production, 14: 677.

Barnard, C. 1972. Register of Australian herbage plant cultivars. 5. Leucaena (a) *Leucaena leucocoephala* cv. Peru, cv. El Salvador. Townsville, Queensland, Australia: CSIRO. 168–170.

Bauer, D. 1981. Infection of legumes by rhizobia. Annual Review of Plant Physiology, 32: 407–449.

Bawagan, B.O., and Villanueva, E.P. 1976. Prehydrolysis kraft pulping of some fast growing wood species for dissolving pulp — Cooperative Project C1-74 (Cd-Cp-2): 26. College, Laguna, Philippines: FPRDI (Forest Products Research and Development Institute).

Bawagan, P.V. 1982. Improved earth kiln carbonization method. NSTA Technology Journal, 7(1): 44.

Bawagan, P.V., and Semana, J.A. 1979. Feasibility study of the utilization of man made forests for generating electricity, 2 x 37.5 MW. College, Laguna, Philippines: FORPRIDECOM (Forest Products Research and Industries Development Commission).

1980. Dendro thermal power plants vs. oil fired power plants under Philippine conditions. NSTA Technology Journal, 5(4): 17–24.

Benge, M.D. 1979. Field trip report to Indonesia, Oct. 11–23. Washington, D.C., USA: AID (Agency for International Development).

Benge, M.D., and Curran, H. 1976. BAYANI (giant ipil-ipil, *Leucaena leucocephala*): a source of fertilizer, feed and energy for the Philippines. Washington, D.C., USA: AID (Agency for International Development). April.

Bennet, H.H. 1939. Soil conservation. New York, USA, and London, England: McGraw-Hill Book Company, Inc.

Bindon, B.M., and Lamond, D.R. 1966. Examination of tropical legumes for deleterious effects on animal production. Proceedings Australian Society of Animal Production, 6: 169.

Blunt, C.G. 1976. Preliminary cattle grazing trials on irrigated *Leucaena leucocephala* and pangola grass in the Ord Valley, N.W. Australia. Proceedings Australian Society of Animal Production, 11: 10.

1978. Production from steers grazing nitrogen fertilized irrigated pangola grass in the Ord Valley. Tropical Grasslands, 12: 90–96.

Blunt, C.G., and Jones, R.J. 1977. Steer liveweight gains in relation to the proportion of time on *Leucaena leucocephala* pastures. Tropical Grasslands, 11(2): 159–164.

Bowen, M.R. 1981. *Acacia mangium*: a note on seed collection, handling and storage. Sabah, Malaysia: Forest Research Centre, FAO UNDP Project MAL 78/009, Seed Series 3: 18 p.

Bowen, M.R., and Eusebio, T.V. 1981a. *Acacia mangium*: updated information on seed collection, handling and storage. Sabah, Malaysia: Forest Research Centre, FAO UNDP Project MAL 78/009, Seed Series 5: 26 p.

1981b. *Albizia falcataria*: information on seed collection, handling and germination testing. Sabah, Malaysia: Forest Research Centre, FAO UNDP Project MAL 78/009, Seed Series 4: 12 p.

in press. *Acacia mangium* seed harvests 1982. Sabah, Malaysia: Forest Research Centre.

FAO UNDP Project MAL 78/009 Working Paper 15. 23 p.

Bray, R A. 1980. Seedling characteristics of cultivars of *Leucaena leucocephala*. Australian Journal of Experimental Agriculture and Animal Husbandry, 20: 327–329.

1981. *Leucaena leucocephala* – genetics, breeding and evaluation. In CSIRO. Division of Tropical Crops and Pastures. Annual Report. Townsville, Queensland, Australia: CSIRO. 33–35.

Brewbaker, J L. 1954. Incompatibility in autotetraploid. Genetics, 39: 307–316.

1958. Self-compatibility in tetraploid strains of *Trifolium hybridum*. Hereditas, 44: 545–553.

1967. Distribution and phylogenetic significance of binucleate and trinucleate pollen grains in the angiosperms. American Journal of Botany, 54: 1069–1083.

1980a. Giant leucaena energy tree farm — an economic analysis for the island of Molokai, Hawaii. Honolulu, Hawaii, USA: Hawaii Natural Energy Institute. 90 p.

1980b. What is giant leucaena? Leucaena Research Reports, 1: 4–8.

in press, a. Breeding for disease resistance. In Kommedahl, T., and Williams, P., ed. Challenging Problems in Plant Health. American Phytopathology Society. (in press).

in press, b. Guide to the systematics of the genus *Leucaena* Benth. Allertonia. 3. (in press).

Brewbaker, J L., and Hu, T W. 1981. Nitrogen fixing trees of importance in the tropics. Paper prepared for the Biological Nitrogen Fixation Workshop in Cali, Colombia, March, and in Taichung, Taiwan, September. 11 p.

Brewbaker, J L., and Hutton, E M. 1979. Leucaena versatile tropical tree legume. In Richie, G A., ed. New Agricultural Crops. Boulder, Colorado, USA: Westview Press. 207–259. (appeared also in AAAS (American Association of Advancement of Science) Selected Symposium, 38: 241).

Brewbaker, J L., and Hylin, J W. 1965. Variation in mimosine content among *Leucaena* species and related Mimosaceae. Crop Science, 5: 348–349.

Brewbaker, J L., and Kaye, S. 1981. Mimosine variation in species of the genus *Leucaena*. Leucaena Research Reports, 2: 66–68.

Brewbaker, J L., Plucknett, D L., and Gonzalez, V. 1972. Varietal variation and yield trials of *Leucaena leucocephala* ("koa haole") in Hawaii. Hawaii Agricultural Experiment Station Research Bulletin, 166. 29 p.

Brewbaker, J L., and Styles, B., ed. 1982. Economically important nitrogen fixing tree species. Waimanalo, Hawaii, USA: Nitrogen Fixing Tree Association, NFTA Miscellaneous Publication 82-04.

Brewbaker, J L., Van Den Belt, R., and MacDicken, K. 1981. Nitrogen fixing tree resources: potentials and limitations. In ed., Biological Nitrogen Fixation. Cali, Colombia: CIAT.

Bushby, H V A. 1982. Rhizosphere populations of *Rhizobium* strains and nodulation of *Leucaena leucocephala*. Australian Journal of Experimental Agriculture and Animal Husbandry, 22: 293–298.

Chandler, M R. 1978. Some observations on infection of *Arachis hypogaea* L. by *Rhizobium*. Journal of Experimental Botany, 29: 749–755.

Chang, J C., Tao, Charles C C., and Wong, C J. 1982. Three species of scale insects injurious to 'giant' leucaena. Leucaena Research Reports, 3: 55.

Chang, Yu-Cheng. 1980. Tineid moth and the elongate coccus mute *Leucaena leucocephala*. Leucaena Newsletter, 1: 28.

Cheeke, P R., and Telek, L. 1980. Nutritional evaluation of rats fed liquid protein concentrates from leucaena. Leucaena Newsletter, 1: 45.

Carangal, Apolinario, R., and Alicia, D Catindig. 1955. Mimosine content of locally grown ipil-ipil (*Leucaena glauca*). Philippine Agriculturist, 39: 249–254.

Chen, C P., Ajit, S S., and Evans, T R. 1982. Beef production from three nitrogen fertilized grasses in Peninsular Malaysia. MARDI Research Bulletin, 9: 207–224.

Chen, Ching-Yih, and Chen, Ming-Yih. 1981. Physiological and ecological characteristics of leucaena. Leucaena Research Reports, 2: 45.

Chen, M T., and Lai, Y L. 1981. Effect of leucaena diet on chick growth. Leucaena Research Reports, 2: 47.

Chen, M T., Cheng, T., and Lin, L S. 1981. Feeding efficiency of leucaena leaf meal used in pig ration. Leucaena Research Reports, 2: 46.

Cheng, Wei-Er, Hu, Ta-Wei, and Shen, Tse-An. in press. Nutrient accumulation of leucaena plantation with different spacings. Taiwan Forestry Research Institute Bulletin (in press).

Chiang, Chian-Cheng. 1980a. Problems of planting giant leucaena for wood production in eastern Taiwan. 1. economical value of giant leucaena. Taiwan Forestry Journal, 6(8): 16–22. (in Chinese).

1980b. Problems of planting giant leucaena for wood production in eastern Taiwan. 2. feasibility of planting leucaena on a large scale. Taiwan Forestry Journal, 6(9): 11–16. (in Chinese).

1980c. Problems of planting giant leucaena for wood production in eastern Taiwan. 3. measures for the extension and assistance of planting giant leucaena. Taiwan Forestry Journal, 6(10): 13–15. (in Chinese).

CIAT (Centro Internacional de Agricultura Tropical). 1977. Annual report for 1977. Beef program, soil microbiology section. Cali, Colombia: CIAT. A36–A43.

Chomchalow, N. 1980. *Leucaena* sp. Thai Journal of Agricultural Sciences (Varasara Vittavasat Kan-kaset), 13(2): 161–170. (in Thai).

Chou, C H. 1982. Study of allelopathy with Hengchun vegetation. Leucaena Research Reports, 3: 57.

Cockburn, P.F. 1974. Origin of Sook Plain, Sabah. Malaysian Forester, 37(1), 61–63.

Common, I.F.B., and Beattie, W.M. 1982. Introduced moth *Ithome lassula* Hodges (Lepidoptera: Cosmopterigidae) attacking *Leucaena* in northern Queensland. Journal of the Australian Entomology Society, 21, 195–197.

Compete, R. 1959. Study on the toxicity of *Leucaena glauca* to cattle. Bulletin agricole du Congo Belge et du Ruanda-Burundi, 50, (5), 1311–1320.

Cooksley, D.G. 1974. Growing and grazing *leucaena*. Queensland Agricultural Journal, 100, 258–261.

in press. Effects of planting depth and sowing methods on emergence of leucaena (*Leucaena leucocephala* cv. Peru) seed in a light medium clay. Queensland Journal of Agriculture and Animal Science (in press).

Corby, H.D.L. 1980. Rhizobial root nodules in the classification of the Leguminosae. Harare, Zimbabwe, University of Zimbabwe (formerly University College of Rhodesia and Nyasaland). 163 p. (doctorate thesis).

Cruz, E.M., and Laudencia, I.L. 1978. Screening of feedstuffs as ingredients in the rations of Nile tilapia. Kalikasan, Philippine Journal of Biology, 7(2), 159–164.

Date, R.A., and Halliday, J. 1979. Selecting *Rhizobium* for acid, infertile soils of the tropics. Nature, 277, 62–64.

1980. Relationships between *Rhizobium* and tropical forage legumes. In Summerfield, R.J., and Bunting, A.H., ed., Advances in Legume Science. Kew, England, Royal Botanic Gardens, 597–602.

Decena, A., et al. 1970. Lumber grade recovery of handmills in the Manila and suburban areas. Project 11-70(S-Cp-1)-1. College, Laguna, Philippines, FPRDI (Forest Products Research and Development Institute).

Devendra, C. 1982. Comparative utilisation of *Leucaena* forage by goats and sheep in Malaysia. Paper prepared for the Second Asian-Australian Animal Science Congress, Manila, Philippines, 10–13 November. 15 p.

in press. Nutritive value of *Leucaena leucocephala* cv. Peru in balance and growth studies with goats and sheep. MARDI Research Bulletin (in press).

Dijkman, M.J. 1950. *Leucaena* — a promising soil-erosion-control plant. Economic Botany, 4, 337–349.

Dingayan, A.B., and Fronda, F.M. 1950. Comparative study of the influence of the leaves and young shoots of *Centrosema*, ipil-ipil, and sweet potato as green feed on the growth of chicks. Philippine Agriculturist, 34, 110–113.

D'Mello, J.P.F., and Fraser, K.W. in press. Composition of leaf meal from *Leucaena leucocephala*. Tropical Science (in press).

D'Mello, J.P.F., and Thomas, D. 1978. Nutritive value of dried *leucaena* leaf meal from Malawi — studies with young chicks. Tropical Agriculture (Trinidad), 55, 45–50.

Durzan, D.J. 1979. Progress and promise in forest genetics. Paper prepared for the 50th anniversary conference: Paper Science and Technology — The Cutting Edge, Appleton, Wisconsin, USA, 8–10 May.

Eala, R.C., and Ortiz, F.C. 1978. Lumber recovery study on giant ipil-ipil. College, Laguna, Philippines, FPRDI (Forest Products Research and Development Institute), Special Report.

Eala, R.C., and Salita, A. 1981. Suitability of giant ipil-ipil in weaving looms and parquet flooring. College, Laguna, Philippines, FPRDI (Forest Products Research and Development Institute).

Egara, K., and Jones, R.J. 1977. Effect of shading on the seedling growth of the leguminous shrub *Leucaena leucocephala*. Australian Journal of Experimental Agriculture and Animal Husbandry, 17, 976–981.

Elkan, G.H. 1971. Biochemical and general aspects of the taxonomy of *Rhizobium japonica*. Plant and Soil, special volume, 85–104.

Eng, P.K., Mannetje, L., and Chen, C.P. 1978. Effect of phosphorus and stocking rate on pasture and animal production in Johore, Malaysia. 2. animal live weight changes. Tropical Grasslands, 12, 198–207.

Escolano, E.U., Gonzales, E.V., and Semana, J.A. 1978. Proximate chemical composition of giant ipil-ipil wood from different sources. FORPRIDE Digest, 7(4), 18–22.

Falvey, L. 1976. Productivity of *Leucaena leucocephala* in the Daly Basin, northern territory. Tropical Grasslands, 10, 117–121.

FAO (Food and Agriculture Organization of the United Nations). in press. a. Variation of *Acacia mangium* Willd. based on the work of L. Pedley. Rome, Italy, FAO, FAO/UNDP Project MAL/78/009, Consultant's Report 8. 42 p.

in press. b. Vegetative propagation: in vitro culture based on the work of R.R.B. Leakey. Rome, Italy, FAO, FAO/UNDP Project MAL/78/009, Consultant's Report 10. 37 p.

Farinas, E.C. 1951. Ipil-ipil the alfalfa of the tropics, its establishment, culture and utilization as a fodder and pasture crop. Philippine Journal of Animal Industry, 12, 65–84.

Federer, W.T., and Raghavarao, D. 1975. On augmented designs. Biometrics, 31, 29–35.

Fenton, R., Roger, R.E., and Watt, G.R. 1977. Lowland tropical hardwoods: annotated bibliography of selected species with plantation potential. Wellington, New Zealand, External Aid Division, Ministry of Foreign Affairs, AA 1–17; AF 1–34.

Ferraris, R. 1979. Productivity of *Leucaena leucocephala* in the wet tropics of north Queensland. Tropical Grasslands, 13, 20–27.

Floresca, A.R., Lauricio, F.M., and Versola, L.O. 1978. Mechanical properties of giant ipil-ipil. NSTA Technology Journal, 3(3), 56–59.

Generalla, N.C. 1982. Particleboard production

variables. Paper prepared for the Symposium on Particleboard Technology, Forest Products Research and Development Institute, College, Laguna, Philippines, 29 September.

Gonzales, A., Andrew, C.S., and Pieters, W.H.J. 1980. Foliar symptoms of mineral disorders on *Leucaena leucocephala*. Townsville, Queensland, Australia, CSIRO, Division of Tropical Crops and Pastures, Technical Paper 21.

Gonzalez, V. 1966. Genetics and agronomic studies on the genus *Leucaena* Benth. Honolulu, Hawaii, USA, University of Hawaii (master's thesis).

Gonzalez, V., Brewbaker, J.L., and Hamill, D.E. 1967. Leucaena cytogenetics in relation to the breeding of low mimosine lines. Crop Science, 7, 140 - 143.

Graham, P.H. 1963. Antibiotic sensitivities of the root nodule bacteria. Australian Journal of the Biological Sciences, 16, 557 - 559.

1964. Studies on the utilization of carbohydrates and Krebs cycle intermediates by rhizobia, using an agar plate method. Antonie van Leeuwenhoek Journal of Microbiology and Serology, 30, 68 - 72.

1976. Identification and classification of root nodule bacteria. In Nutman, P.S., ed., Symbiotic Nitrogen Fixation in Plants. Cambridge, England, Cambridge University Press, 99 - 112.

Gray, S.G. 1962. Hot water seed treatment for *Leucaena glauca* (L.) Benth. Australian Journal of Experimental Agriculture and Animal Husbandry, 2, 179 - 180.

1968. Review of research on *Leucaena leucocephala*. Tropical Grasslands, 2, 19 - 30.

Grobbelaar, N., and Clarke, B. 1974. Qualitative study of the nodulating ability of legume species: list 4. Agroplantae, 6, 59 - 64.

Guevarra, A.B. 1976. Management of *Leucaena leucocephala* (Lam.) de Wit for maximum yield and nitrogen contribution to intercropped corn. Honolulu, Hawaii, USA, University of Hawaii, 126 p. (doctorate thesis).

Guevarra, A.B., Whitney, A.S., and Thompson, J.R. 1978. Influence of intra-row spacing and cutting regimes on the growth and yield of leucaena. Agronomy Journal, 70, 1033 - 1037.

Gupta, S.K., Pathak, P.S., Deb Roy, R. in press. Seedling growth of *Leucaena leucocephala* (Lam.) De Wit. 1. effect of seed size. Indian Journal of Forestry (in press).

Halliday, J. 1979. Field responses by tropical forage legumes to inoculation with *Rhizobium*. In Sanchez, P.A., and Tergas, L.A., ed., Pasture Production in Acid Soils of the Tropics. Cali, Colombia, CIAT, 123 - 137.

Halliday, J., and Nakao, P.L. 1982. Symbiotic affinities of woody species under consideration as nitrogen-fixing trees — a resource document. Nitrogen-Fixing Tree Germ Plasm Workshop. Paia, Hawaii, USA, University of Hawaii, NIFTAL Project, 80 p.

Halliday, J., and Pate, J.S. 1976a. Acetylene reduction assay as a means of studying nitrogen fixation in white clover under laboratory and sward conditions. Journal of the British Grassland Society, 31, 29 - 35.

1976b. Symbiotic nitrogen fixation by coralloid roots of the cycad *Macrozamia riedlei*: physiological characteristics and ecological significance. Australian Journal of Plant Physiology, 3, 349 - 358.

Halos, S.C. 1980. Ipil-ipil: the wonder ceases. Canopy International, September.

Hamilton, R.I., Donaldson, L.E., and Lambourne, L.J. 1971. *Leucaena leucocephala* as a feed for dairy cows: direct effect on reproduction and residual effect on the calf and lactation. Australian Journal of Agricultural Research, 22, 681 - 692.

Hathcock, J.N., and Labadan, M.M. 1975. Toxicity of mimosine and *Leucaena leucocephala* extracts to chicken embryo. Nutrition Reports International, 11, 63 - 69.

Hegarty, M.P., Lee, C.P., Christie, G.S., Court, R.D., and Haydock, K.P. 1979. Goitrogen 3-hydroxy-4(1H)-pyridone, a ruminal metabolite from *Leucaena leucocephala*: effects in mice and rats. Australian Journal of Biological Science, 32, 27 - 40.

Hegarty, M.P., Schinckel, P.G., and Court, R.D. 1964. Reaction of sheep to the consumption of *Leucaena glauca* Benth. and to its toxic principle mimosine. Australian Journal of Agricultural Research, 15, 153.

Herridge, D.F. 1982. Assessment of nitrogen fixation. In Vincent, J.M., ed., Nitrogen Fixation in Legumes. New York, USA, Academic Press, 123 - 136.

Hill, G.D. 1971a. *Leucaena leucocephala* for pastures in the tropics. Herbage Abstracts, 41, 111 - 119.

1971b. Studies on the growth of *Leucaena leucocephala*. 3. production under grazing in the New Guinea lowlands. Papua and New Guinea Agricultural Journal, 22, 73 - 76.

Hogberg, P., and Kvarnstrom, M. 1982. Nitrogen fixation by the woody legume *Leucaena leucocephala* in Tanzania. Plant and Soil, 66, 21 - 28.

Holmes, J.H.G. 1981. Toxicity of *Leucaena leucocephala* for steers in the wet tropics. Tropical Animal Health and Production, 13, 94 - 100.

Hsieh, Huann-Ju. 1980. Seedling damping-off of *Leucaena* in Taiwan. Leucaena Newsletter, 1, 28.

1982. Diseases of leucaena in Taiwan. Leucaena Research Reports, 3, 58.

Hu, Ta-Wei. 1976. New aspects of *Leucaena leucocephala*. Forest, 1, 74 - 77. Taipei, Taiwan, College of Chinese Culture (in Chinese).

1979. Role of *Leucaena leucocephala* in the production of agricultural crops. In Agricultural Associations of China, Proceedings of the Annual Meeting of the Agricultural Association of China. Taipei, Taiwan, Agricultural Associations of China (in Chinese with English summary).

1980. How to plant *Leucaena leucocephala*. Taipei, Taiwan, Taiwan Forestry Research Insti-

tute, Extension Pamphlet 38 (in Chinese).

Hu, Ta-Wei, and Cheng, W.E. 1980a. Effect of liming on the growth and nutrient levels of leucaena. Leucaena Newsletter, 1, 31–32.

1980b. Effect of liming on the growth and nutrient levels of *Leucaena leucocephala*. Quarterly Journal of Chinese Forestry, 13(4), 89–99 (in Chinese with English summary).

1981. Growth and nutrition levels of *Leucaena leucocephala*: response to lime and phosphorus on acid soil. Leucaena Research Reports, 2, 48–49.

Hu, Ta-Wei, Cheng, W.E., and Shen, T.A. 1981. Growth and nutrition response of *Leucaena leucocephala* to lime and phosphorus. In Agricultural Associations of China, Proceedings of the Annual Meeting of Agricultural Associations of China. Taipei, Taiwan, Agricultural Associations of China (in Chinese with English summary).

Hu, Ta-Wei, and Kiang, Tao. 1982. Wood production of spacing trial varieties of leucaena in Taiwan. Leucaena Research Reports, 3, 62.

Hu, Ta-Wei, Kiang, Tao, and Shih, Wen-Chun. 1977. Introduction of new varieties of *Leucaena leucocephala*. In Agricultural Associations of China, Proceedings of the Annual Meeting of Agricultural Associations of China. Taipei, Taiwan, Agricultural Associations of China (in Chinese).

1980. Growth of planted *Leucaena leucocephala* in Taiwan. Taipei, Taiwan, Taiwan Forestry Research Institute, Bulletin 335 (in Chinese with English summary).

Hu, Ta-Wei, Kiang, Tao, Shih, Wen-Chun, and Yu, Nai-Kuang. in press. Growth of leucaena in spacing trial plantations. Taipei, Taiwan, Taiwan Forestry Research Institute, Bulletin (in press) (in Chinese with English summary).

Hu, Ta-Wei, and Liu, Chih-Cheng. 1981. Vegetative propagation of *Leucaena* by leafy cuttings under mist spray. Leucaena Research Reports, 2, 50.

Hu, Ta-Wei, and Shih, Wen-Chun. 1982. Growth of different varieties of leucaena in Taiwan. Leucaena Research Reports, 3, 62.

Hu, Ta-Wei, Shih, Wen-Chun, and Chien, Ching-Der. in press. Growth of leucaena at different elevations of different regions. Taipei, Taiwan, Taiwan Forestry Research Institute, Bulletin (in press) (in Chinese with English summary).

Huang, Hung-Cheh, and Tsai, Tung-Pao. 1981. Forests for the production of fiber materials in Taiwan. In Afforestation Association of China, Proceedings of the 10th Anniversary of Afforestation Association of China. Taipei, Taiwan, Afforestation Association of China, 88–93 (in Chinese).

Hutton, E.M. 1981. Natural crossing and acid tolerance in some *Leucaena* species. Leucaena Research Reports, 2, 2–4.

Hutton, E.M., and Beattie, W.M. 1976. Yield characteristics in three bred lines of the legume *Leucaena leucocephala*. Tropical Grasslands, 10, 187–194.

Hutton, E.M., and Bonner, I.A. 1960. Dry matter and protein yield in four strains of *Leucaena glauca* Benth. Journal of the Australian Institute of Agricultural Science, 26, 276–277.

Hutton, E.M., and Eddie, T.Z. 1982. *Leucaena esculenta* and *L. trichodes*: some similarities and differences. Leucaena Research Reports, 3, 12–13.

Hutton, E.M., and Gray, S.G. 1959. Problems in adopting *Leucaena glauca* as a forage for the Australian tropics. Empire Journal of Experimental Agriculture, 27(107), 187–196.

Incong, M.E., Bawagan, B.O., Cruz, M.P., and Villanueva, E.P. 1978. Giant ipil-ipil dissolving pulp production. College, Laguna, Philippines, FORPRIDECOM (Forest Products Research and Industries Development Commission).

Jai, Su-Yung, Hwang, C.Y., and Hsiung, J.C. 1982. Feasibility of producing leucaena press-lam and its use as a stock for making furniture. Leucaena Research Reports, 3, 63.

Jen, I-An. 1980. Economic feasibility of planting *Leucaena* for wood in Taiwan. Leucaena Newsletter, 1, 31.

Johnson, C.R., and Menge, J.A. 1982. Mycorrhiza may save fertilizer dollars. American Nurseryman, 15 January.

Jones, N. 1981. Report on Philippines study tour. Sabah, Malaysia, Forest Research Centre, FAO-UNDP Project MAL 78/008 Working Paper 5, 37 p.

Jones, R.J. 1970. Establishment of *Leucaena leucocephala*. In CSIRO, Division of Tropical Pastures, Annual Report. Townsville, Queensland, Australia, CSIRO, 58–59.

1973. Animal performance on *Leucaena leucocephala*. In CSIRO, Division of Tropical Agronomy, Annual Report. Townsville, Queensland, Australia, CSIRO, 15.

1974. Comparison of four lines of *Leucaena* under cutting. In CSIRO, Division of Tropical Agronomy, Annual Report. Townsville, Queensland, Australia, CSIRO, 20.

1975. *Leucaena* establishment studies. In CSIRO, Division of Tropical Agronomy, Annual Report. Townsville, Queensland, Australia, CSIRO, 74–75.

1979. Value of *Leucaena leucocephala* as a feed for ruminants in the tropics. World Animal Review, 31, 13–23.

1981. Does ruminal metabolism of mimosine and DHP explain the absence of *Leucaena* toxicity in Hawaii? Australian Veterinary Journal, 57, 55–56.

Jones, R.J., and Aliyu, A.S. 1976. Effect of *Eleusine indica*, herbicides and activated charcoal on the seedling growth of *Leucaena leucocephala* cv. Peru. Tropical Grasslands, 10, 195–203.

Jones, R.J., Blunt, C.G., and Holmes, J.H.G. 1976. Enlarged thyroid glands in cattle grazing *Leucaena* pastures. Tropical Grasslands, 10(2), 113–116.

Jones, R.J., Blunt, C.G., and Nurnberg, B.I. 1978.

Toxicity of *Leucaena leucocephala*: the effect of iodine and mineral supplements on penned steers fed a sole diet of *Leucaena*. Australian Veterinary Journal, 54, 387 - 392.

Jones, R.J., and Egara, K. 1976. *Leucaena* establishment studies. In CSIRO, Division of Tropical Crops and Pastures, Annual Report. Townsville, Queensland, Australia, CSIRO, 8.

Jones, R.J., and Jones, R.M. 1979. Agronomy of *Leucaena leucocephala*. Townsville, Queensland, Australia, CSIRO, Division of Tropical Crops and Pastures, Information Service Sheet 41 - 1, December.

1982. Observations on the persistence and potential for beef production of pastures based on *Trifolium semipilosum* and *Leucaena leucocephala* in subtropical coastal Queensland. Tropical Grasslands, 16, 24 - 29.

Jones, R.J., Jones, R.M., and Cooksley, D.G. 1982. *Leucaena leucocephala*. Townsville, Queensland, Australia, CSIRO, Division of Tropical Crops and Pastures, Information Service Sheet 41 - 1.

Jones, R.J., and Megarrity, R.G. 1981. Contrasting responses of goats fed leucaena in Australia and Hawaii. Leucaena Research Reports, 2, 15 - 17.

in press. Comparative toxicity responses of goats fed *Leucaena leucocephala* in Australia and Hawaii. Australian Journal of Agricultural Research (in press).

Jones, R.J., and Winter, W.H. 1982. Serum thyroxine levels and liveweight gain of steers grazing leucaena pastures. Leucaena Research Reports, 3, 2 - 3.

Jones, R.M., and Harrison, R.L. 1980. Survival of individual plants of *Leucaena leucocephala* in grazed stands. Tropical Agriculture (Trinidad), 57, 265 - 266.

Jones, R.M., and Jones, R.J. 1979. Comparison of two leucaena cultivars. In CSIRO, Division of Tropical Crops and Pastures, Annual Report. Townsville, Queensland, Australia, CSIRO, 7.

1981. Effect of *Leucaena leucocephala* on reproduction in beef cattle. In CSIRO, Division of Tropical Crops and Pastures, Annual Report. Townsville, Queensland, Australia, CSIRO, 98.

Kanazawa, Y., Sato, A., and Orsolino, R.S. 1982. Aboveground biomass and the growth of giant ipil-ipil plantations in northern Mindanao Island, Philippines. Japan Agricultural Research Quarterly, 15(3), 209 - 217.

Kiang, Tao. 1981. Discussion and suggestion on extension of planting new varieties of *Leucaena leucocephala*. In Afforestation Association of China, Proceedings of the 10th Anniversary of Afforestation Association of China. Taipei, Taiwan, Afforestation Association of China, 66 - 71 (in Chinese).

Kiang, Tao, Rin, Un-Ching, and Tai, Kwang-Yao. 1980. Comprehensive research program on *Leucaena* in Taiwan. Leucaena Newsletter, 1, 34.

Kinch, D.M., and Ripperton, J.C. 1962. Koa haole, production and processing. Hawaii Agricultural Experiment Station Technical Bulletin, 129. 58 p.

Klankamsorn, B., and Charupatana, T. 1981. Using Landsat imagery to investigate the changes of forest land use. Bangkok, Thailand, Royal Forest Department. 23 p.

Korvanich, A. 1982. *Leucaena leucocephala*. Thai Journal of Sak Thong (Varasara Sak Thong), January - March, 7(1), 1 - 9 (in Thai).

Ku, Y.C., and Lin, S.J. 1982. Leucaena wood fibers for animal feeding. Leucaena Research Reports, 3, 64.

Ku, Y.C., Pan, T.T., and Wang, K.T. 1981. Semichemical pulping of leucaena wood. Leucaena Research Reports, 2, 51.

Kuo, Y.L., Chou, C.H., and Hu, T.W. 1982. Allelopathic potential of *Leucaena leucocephala*. Leucaena Research Reports, 3, 65.

Labadan, M.M. 1969. Effects of various treatments and additives on the feeding value of ipil-ipil leaf meal in poultry. Philippine Agriculturist, 53, 392 - 401.

Ladrach, W.E. 1980. Tree growth response to the application of phosphorus, nitrogen, and boron at the time of planting in the departments of Cauca and Valle. Cali, Colombia, Carton de Colombia, July, Research Report 59.

Laxamana, M. 1981. Drying of giant ipil-ipil lumber and poles. Project NSDB-FORD 7733 En — terminal report. College, Laguna, Philippines, FPRDI (Forest Products Research and Development Institute).

Laxamana, N.B. 1981. Calorific value and specific gravity of giant ipil-ipil (PCARR-IBRD project 5.1). College, Laguna, Philippines, FPRDI (Forest Products Research and Development Institute) (unpublished manuscript).

Lee, Bryant P.K. 1980. Feeding value of *Leucaena* seeds for swine, chickens and rats. Leucaena Newsletter, 1, 34.

1981. Nutrient composition of leucaena in Taiwan. Leucaena Research Reports, 2, 52.

Lee, Bryant P.K., and Yang, Y.F. 1982. Leucaena seed as a feed ingredient for broiler chicks. Leucaena Research Reports, 3, 66.

Lee, T.Y., Chen, M.P., and Kao, S.F. 1957. Experiment on the *Leucaena* seed meat instead of soybean oil cake as protein supplement for hogs. Agricultural Research, 6(4), 1 - 6 (in Chinese).

Letts, G.A. 1963. *Leucaena glauca* and ruminants. Australian Veterinary Journal, 39, 287 - 288.

Librojo, N.T., and Hathcock, J.N. 1974. Metabolism of mimosine and other compounds from *Leucaena leucocephala* by the chicken. Nutrition Reports International, 9(3).

Lim, G. 1979. *Rhizobium* and nodulation of legumes in Singapore. In Broughton, W.J., et al. ed., Proceedings of the Symposium on Soil Microbiology and Plant Nutrition. Kuala Lumpur, Malaysia, University of Malaya Press, 159 - 175.

Lim, G., and Burton, J.L. 1982. Nodulation status of the Leguminosae. In Broughton, W.J., ed., Nitrogen Fixation, Vol. 2: *Rhizobium*. Oxford, England, Oxford University Press.

Lim, G., and Ng, H.L. 1977. Root nodules of some

tropical legumes in Singapore. Plant and Soil, 46(2), 317–327.

Lim, G., and Ng, H.S. 1981. Some observations on rhizobia isolates of legumes in Singapore. Journal of the National Academy of Sciences, 1979, 8, 1–5.

Lin, Jung-Yaw. 1982. Toxic nature of non-protein amino acid. Leucaena Research Reports, 3, 67.

Little, D.A., and Hamilton, R.I. 1971. *Leucaena leucocephala* and thyroid function of newborn lambs. Australian Veterinary Journal, 47, 457–458.

Lohan, O.P., Lall, D., Pal, R.N., and Negi, S.S. 1980. Note on tannins in tree fodder. Indian Journal of Animal Sciences, 50, 881–883.

Lopez, P.L., Sayaboc, V.S., and Deanon, A.S. 1979. Philippine Agriculturist, 62, 116–129.

Low, M.T. in preparation. *Acacia mangium* height, growth variation on different soil catenas in Ulu Kukut F.R. Sabah, Malaysia. Forest Research Centre, FAO/UNDP-Project MAL/78/009, Working Paper 17.

Lowry, J.B., Tangendjaja, B., and Maryanto. in press. Autolysis of mimosine to 3-hydroxy-4-(1H)pyridone in green tissues of *Leucaena leucocephala*. Journal of the Science of Food and Agriculture (in press).

Lu, Chin-Ming, and Hu, Ta-Wei. 1981. Biomass production of two-year old spacing trial plantation of leucaena in Taiwan. Leucaena Research Reports, 2, 53–54.

Mackay, J.H.E. 1976. Register of Australian plant cultivars. B: Legumes. 5: *Leucaena leucocephala* (Lam.) de Wit cv. Cunningham. Journal of Australian Institute of Agricultural Science, 42, 254–255.

Manidool, C. 1968. Records of introduced forage crops in Thailand. Journal of the Thailand Veterinary Association, 1, 34–59 (in Thai).

1971. Digestibility of local strains of leucaena. Journal of the Thailand Veterinary Association, 2, 55–60 (in Thai).

1981. Protein-rich feed from leucaena in Thailand. Asian Livestock, 6(10), 90.

Manidool, C., Ruenpakvudh, S., and Sirikertiyanond, N. 1981. Effect of spacing on the yields of three strains of leucaena. Journal of the Thailand Veterinary Association, 32, 146–152 (in Thai).

Manidool, C., and Torsakul, P. 1977. Yields and nutritive value of ten leucaena strains. Thailand Journal of Agricultural Science, 10, 509–516 (in Thai).

Matches, A.G., ed. 1973. Allelochemistry and forage crops. Proceedings of the Crop Science Society of America, 4–5.

Megarrity, R.G. 1978. Automated colorimetric method for mimosine in *Leucaena* leaves. Journal of the Science of Food and Agriculture, 29, 182–186.

1981. Rapid estimation of DHP in urine. Leucaena Research Reports, 2, 16.

Megarrity, R.G., and Jones, R.J. in press. Toxicity of *Leucaena leucocephala* in ruminants: the effect of supplemental thyroxine on goats fed a sole diet of leucaena. Australian Journal of Agricultural Research (submitted).

Mendoza, R.C., Altamirano, T.P., and Javier, E.Q. 1975. Herbage crude protein and digestible dry matter yield of ipil-ipil (*Leucaena leucocephala* cv. Peru) in hedgerows. Paper prepared for the Philippine Society of Animal Science annual meeting.

Mengel, K., and Kirkley, E.A. 1978. Principles of plant nutrition. USA, International Potash Institute.

Metzner, J.K. 1976. Lamtoronisasi: an experiment in soil conservation. Bulletin of Indonesian Economic Studies, 12(1), March, 103–109.

1977. Disequilibrium of agriculture regions in the eastern lesser Sunda Islands. Heidelberg, Germany, South Asia Institute.

Misra, S.M., Patil, B.D., Pathak, P.S., and Singh, R.P. in press. Effect of silvipastoral systems on some physical and chemical properties of calcareous soils. Journal of the Indian Society of Soil Science (submitted).

Moffett, A.A., and Nixon, K.M. 1974. Effects of self-fertilisation on green wattle (*Acacia decurrens*) and black wattle (*Acacia mearnsii*). Johannesburg, South Africa, Wattle Research Institute, Report 1973–74, 66–84.

Nabors, N.W. 1976. Using spontaneously occurring and induced mutations to obtain agriculturally useful plants. Bio Science, 26(12), December.

NAS (National Academy of Sciences). 1977. Leucaena: promising forage and tree crop for the tropics. Washington, D.C., USA, NAS.

1979. Tropical legumes: resources for the future. Washington, D.C., USA, NAS. 331 p.

1980. Firewood crops: shrub and tree species for energy production. Washington, D.C., USA, NAS. 237 p.

in press. Reforesting the tropics — the promise of *Acacia mangium* and other acacias of the humid tropics. Washington, D.C., USA, NAS.

National Electrification Administration. 1982. Energy from biomass: the Philippine experience, volume 2. Manila, Philippines, National Electrification Administration.

Ng, F.S.P. 1980. Legumes in forestry. In Universiti Pertanian Malaysia, Proceedings of the Symposium: Legumes in the Tropics. Serdang, Malaysia, Universiti Pertanian Malaysia, 449–455.

Nicholson, D.I. 1981. Natural occurrence and conservation status of *Acacia mangium* in Australia. Queensland, Australia, Department of Forestry, Technical Note 5. 7 p.

Norani, Ahmad, and Ng, F.S.P. 1981. Growth of *Leucaena leucocephala* in relation to soil pH, nutrient levels and *Rhizobium* concentration. Leucaena Research Reports, 2, 5–10.

Norris, D.O. 1956. Legumes and the *Rhizobium* symbiosis. Empire Journal of Experimental Agriculture, 24, 247–270.

1965. Acid production by *Rhizobium*: a unifying concept. Plant and Soil, 22, 143 – 166.

1973. Seed pelleting to improve nodulation of tropical and subtropical legumes. 5. the contrasting response to lime pelleting of two *Rhizobium* strains on *Leucaena leucocephala*. Australian Journal of Experimental Agriculture and Animal Husbandry, 13, 98 – 101.

Oakes, A.J. 1968. *Leucaena leucocephala*: description, culture and utilization. Advances in Frontier Plant Science, 20, 1 – 114.

Oakes, A.J., and Skov, O. 1962. Some woody legumes as forage crops for dry tropics. Tropical Agriculture (Trinidad), 39, 281 – 287.

Office of Livestock Development Project. 1981. Annual report. 1981. Bangkok, Thailand, Department of Livestock Development, Ministry of Agriculture (in Thai).

Ong, S.H., and Tham, C.K. 1980. Preliminary study on growth and wood density of *Albizia falcataria*. In Forest Research Centre, Bi-Annual Report of the Forest Research Centre, 1979 – 80. Sabah, Malaysia, Forest Research Centre, 152 – 159.

Pablo, A.A., Lajara, E.A., Alvero, G.S., and Generalla, N.C. 1981. Urea-formaldehyde bonded giant ipil-ipil particleboard. PCARR-IBRD Project 5.3. College, Laguna, Philippines, FPRDI (Forest Products Research and Development Institute).

Padgett, C.A., and Ivey, W.P. 1959. Coturnix quail as a laboratory research animal. Animal Science, 129, 267 – 268.

Palafox, H.L. 1948. Use of fresh green koa haole leaves in chick rations. Poultry Science, 27, 558 – 561.

Parera, V. 1980. Lamtornisasi in Kabupaten Sikka. Leucaena Newsletter, 1, July, 13 – 14.

1982. Cara Penanaman dan Pemeliharaan Lamtoro di Kabupaten Sikka — NTT (Planting and management techniques of lamtoro in Sikka district — NTT). Paper prepared for the Seminar Nasional Lamtoro I, Jakarta, Indonesia, 23 – 25 August.

Partridge, I.J., and Ranacou, E. 1973. Yields of *Leucaena leucocephala* in Fiji. Tropical Grasslands, 7, 327 – 329.

Pathak, P.S., and Deb Roy, R. 1975. Seedling growth as affected by sowing depth in *Leucaena leucocephala* (Lam.) De Wit. GEOBIOS 2, 78 – 79.

Pathak, P.S., Deb Roy, R., and Misra, C.M. 1974. Growth of *Leucaena leucocephala* intersown with four grasses. In IGFRI (Indian Grassland and Fodder Research Institute), Annual Report. Jhansi, India, IGFRI.

Pathak, P.S., Deb Roy, R., and Rai, P. 1974. Autoecology of *Leucaena leucocephala* (Lam.) De Wit. 1: seed polymorphism and germination. Tropical Ecology, 15(12), 1 – 10.

Pathak, P.S., Gupta, S.K., and Deb Roy, R. 1981. Production of aerial biomass in *Leucaena leucocephala* (Lam.) De Wit. Indian Forester, 107(7), 416 – 419.

Pathak, P.S., and Patil, B.D. 1981. Production performance of Koo-babool (*Leucaena leucocephala* (Lam.) De Wit. with special reference to its giant varieties. Paper prepared for the National Seminar on Koo-babool, Urulikanchan, Pune, 26 – 27 June.

Pathak, P.S., Rai, M.P., and Deb Roy, R. 1981. Seed weight affecting early seedling growth attributes in *Leucaena leucocephala* (Lam.) De Wit. Van Vigyan, 19(3), 97 – 101.

in press. Seedling growth of *Leucaena leucocephala* (Lam.) De Wit. 1: effect of shading. Indian Journal of Forestry (in press).

Pathak, P.S., Rai, P., and Deb Roy, R. 1980. Forage production from Koo-babool (*Leucaena leucocephala* (Lam.) De Wit. 1: effect of plant density, cutting intensity and interval. Forage Research, 6, 83 – 90.

Pedley, L. 1978. Revision of *Acacia* in Queensland. Brisbane, Australia, Queensland Herbarium, Austrobaileya, 1(2). 234 p.

Perez-Guerrero, Z.J. in press. Preservation of *Leucaena* by the ancestral cultures of Mexico. An ecological – historical perspective. Turrialba, Costa Rica, CATIE (Centro Agronómico Tropical de Investigación y Enseñanza.

Prussner, K. 1981. Pertanian Terpadu Berdasarkan *Leucaena leucocephala* untuk agroforestry dan untuk Mengatasi Masalah Perladangan. Paper prepared for the Seminar Agroforestry dan Pengendalian Perladangan, Balai Penelitian Hutan, Bogor, Indonesia, 2 – 4 November.

1982. Penanggulangan Tanah Kritis: Contoh-contoh di Nusa Tenggara Timur. Paper prepared for the Seminar Nasional Lamtoro I, Jakarta, Indonesia, 23 – 25 August.

Rai, P., Pathak, P.S., and Deb Roy, R. in press. Seedling growth of *Leucaena leucocephala* (Lam.) De Wit. Effect of sowing season. Indian Journal of Ecology (in press).

Rayudu, G.V.N., Kadirvel, R., Vohra, P., and Krtzer, F.H. 1970. Effect of various agents in alleviating the toxicity of tannic acid for chickens. Poultry Science, 49, 1323 – 1326.

Reis, P.J., Tunks, D.A., and Hegarty, M.P. 1975. Fate of mimosine administered orally to sheep and its effectiveness as a defleecing agent. Australian Journal of Biological Science, 28, 495 – 501.

Ritchey, K.D., Souza, D.M.G., Lobato, E., and Correa, O. 1980. Calcium leaching to increase rooting depth in a Brazilian savannah oxisol. Agronomy Journal, 72, 40 – 44.

Rocafort, J.E., Floresca, A.R., and Siopongco, J.O. 1971. Fourth progress report on the specific gravity of Philippine woods. Philippine Architecture (Engineering and Construction Record), 18(5).

Romm, J. 1979. Intensive fuelwood cultivation. Paper prepared for the A & P Agricultural and Resources Staff Seminar, Ford Foundation, Delhi, India, 15 July.

Ross, E., and Springhall, J.A. 1963. Evaluation of ferrous sulphate as a detoxifying agent for

mimosine in *Leucaena glauca* rations for chickens. Australian Veterinary Journal, 39, 394–395.

Ross, E., Wayman, O., and Oishi, F.G. 1980. Use of Japanese quail to study the effect of *Leucaena leucocephala* and mimosine on egg production. Proceedings of the American Society of Animal Sciences, Western Section, 31, 129–132.

Sadoval, J.R. 1954. Influence of 5 and 10 parts ipil-ipil leaf meal in the College laying ration. Philippine Agriculturist, 38, 574–582.

Sampet, C. 1980. Effect of height and frequency of cutting *Leucaena leucocephala*. Chiang Mai, Thailand, Chiang Mai University, Faculty of Agriculture, Research Report. 3 p.

1982. Effect of plant density on yield and nutritive value of leucaena. Chiang Mai, Thailand, Chiang Mai University, Faculty of Agronomy (in Thai).

Sampet, L., and Pattaro, U. 1979. Comparative productivity of four strains of *Leucaena leucocephala* under different cutting regimes. Thai Journal of Agricultural Science, 12, 291–300.

Sanchez, P.A., and Salinas, J.G. 1981. Low-input technology for managing oxisols and ultisols in tropical America. Advances in Agronomy, 34, 279–406.

Savory, R. 1979. *Leucaena leucocephala* (Lam.) de Wit: varietal evaluation and agronomy. London, England, University of London (doctorate thesis).

Seawright, A.A. 1963. *Leucaena glauca* in Queensland. Australian Veterinary Journal, 39, 211.

Semana, J.A., and Bawagan, P.V. 1979. Feasibility study of the utilization of man-made forests for generating electricity. 3: 10 MW. College, Laguna, Philippines, FORPRIDECOM (Forest Products Research and Industries Development Commission).

Semana, J.A., Bawagan, P.V., Siriban, F.R., and Mendoza, V. 1977. Feasibility study of the utilization of man-made forest for generating electricity. 1: 75 MW. College, Laguna, Philippines, FORPRIDECOM (Forest Products Research and Industries Development Commission).

Semana, J.A., and Lasmarias, V.B. 1975. Production of hardboard from Peruvian ipil-ipil dissolving pulp production. College, Laguna, Philippines, FPRDI (Forest Products Research and Development Institute).

Semana, J.A., Lasmarias, V., and Pamplona, B. 1981a. Kraft pulping studies on one-year giant ipil-ipil strains. College, Laguna, Philippines, FPRDI (Forest Products Research and Development Institute).

1981b. Kraft pulping studies on two-year old giant ipil-ipil strains. College, Laguna, Philippines, FPRDI (Forest Products Research and Development Institute).

Shaw, N.H. 1965. Weed control in *Leucaena leucocephala*. In CSIRO, Division of Tropical Pastures, Annual Report. Townsville, Queensland, Australia, CSIRO, 42.

1968. In CSIRO, Division of Tropical Pastures, Annual Report. Townsville, Queensland, Australia, CSIRO, 11, 13.

Shih, Wen-Chun, and Hu, Ta-Wei. 1981. Yields of forage of *Leucaena leucocephala* in Taiwan. Leucaena Research Reports, 2, 55–56.

1982. Yields of forage of *Leucaena leucocephala*. Taipei, Taiwan, Taiwan Forestry Research Institute, Bulletin 368 (in Chinese with English summary).

Siriban, F.R., German, E.C., and Mata, P.G. 1981. Study on the preservative treatment of round and sawn giant ipil-ipil. Project NSDB-FORD 7731 En. College, Laguna, Philippines, FPRDI (Forest Products Research and Development Institute).

Smith, I.K., and Fowden, L. 1966. Study of mimosine toxicity in plants. Journal of Experimental Biology, 17(53), 750–761.

Sobale, B.N., Kharat, S.T., Prasad, V.L., Joshi, A.L., Rangnekar, D.V., and Deshmukh, S.S. 1978. Nutritive value of *Leucaena leucocephala* for growing bull calves. Tropical Animal Health and Production, 10, 237–241.

Springhall, J.A., and Ross, E. 1965a. Preliminary studies with poultry rations for the territory of Papua and New Guinea. 1: grower rations with copra, sago and *Leucaena leucocephala*. Papua and New Guinea Agricultural Journal, 17, 117–121.

1965b. Preliminary studies with poultry rations for the territory of Papua and New Guinea. 2: layer rations with copra, sago, and *Leucaena*. Papua and New Guinea Agricultural Journal, 17, 122–126.

Stobbs, T.H. 1972. Suitability of tropical pastures for milk production. Tropical Grasslands, 6, 67–69.

Streets, R.J. 1962. Exotic trees of the British Commonwealth. Oxford, England, Clarendon Press. 765 p.

Tai, Kuang-Yao, Kiang, Tao, Hu, Ta-Wei, and Wang, Tze-Ting. 1982. Utilization of leucaena. Taipei, Taiwan, CAPD (Council for Agricultural Planning and Development), Forestry Series 3. 39 p. (in Chinese).

Tai, Kuang-Yao, Rin, Un-Ching, and Kiang, Tao. 1980. Extension planting and research activities by private corporation in Taiwan. Leucaena Newsletter, 1, 35.

Takahashi, M., and Ripperton, J.C. 1949. Koa haole (*Leucaena glauca*): its establishment, culture and utilization as a forage crop. Hawaii Agricultural Experiment Station Technical Bulletin, 100.

Tamolang, F.N., Valbyena, R.R., Meniado, J., and de Vela, B. 1957. Fiber dimensions of certain Philippine broadleaved woods and bamboos. TAPPI (Technical Association of the Pulp and Paper Industry), 40(8), 671–676.

Tan, K.C., and Jones, N. 1982. Fast growing hardwood plantation on logged-over forest sites in Sabah. Paper prepared for the Malaysian Forestry Conference, Sandakan, Sabah, Malaysia, August.

Tang, Jung-Lei. 1981. Properties of wood from

planted, short rotation, fast-grown leucaena in Taiwan. Leucaena Research Reports, 2: 57.

Tang, Jung-Lei, and Ma, Tze-Ping. 1982. Effect of plantation population density on wood properties and quality of wood-based composition board from leucaena in Taiwan. Leucaena Research Reports, 3: 68–69.

Telek, L. 1979. Preparation of leaf protein concentrates in lowland humid topics. Tropical Foods, 2: 659–683.

in press. Preparation of leaf protein concentrates from *Leucaena leucocephala*. Leucaena Research Reports, 3 (in press).

Ten Dam, H. 1950. Nita dan Sekitarnya: Masyarakat Feodal dan Meninggikan Kemakmuran. Bogor, Indonesia, Fakultas Pertanian Bogor, Bahagian Ilmu Ekonomi Pertanian, Pengumuman, 2, September.

Tham, C.K. 1977. Introduction to a plantation species *Acacia mangium*. In Malaysian Forestry Association, Proceedings of the 6th Malaysian Forestry Conference, Volume 2. Kuching, Sarawak, Malaysia, Malaysian Forestry Association.

1980. *Acacia mangium*: a plantation species for *Imperata cylindrica* grassland in Sabah. Paper prepared for the International Union of Forestry Research Organizations Symposium on Genetic Improvement and Production of Fast-Growing Species. 14 p.

Tham, C.K., and Liew, T.C. 1977. Prospects of forest plantation in the tropics with particular reference to Sabah. Paper prepared for the Commonwealth Scientific and Industrial Research Organization Pulp and Paper Project Seminar, Kuching, Malaysia, 7–10 November.

Tham, K.C., Wong, C.C., and Ajit, S.S. 1977. Establishment of *Leucaena leucocephala* on acid inland soils of Peninsular Malaysia. 1. effect of lime, inoculation pelleting and phosphorus on the establishment of *L. leucocephala*. MARDI Research Bulletin, 5, 10–20.

Thanjan, D.K. 1967. Biochemical effects of *Leucaena leucocephala* on Japanese quail and the effect of supplementing vitamins and amino acids to overcome toxicity. Honolulu, Hawaii, USA, University of Hawaii. 59 p. (master's thesis).

Trinnick, M.J. 1965. *Medicago sativa* nodulation with *Leucaena leucocephala* root-nodule bacteria. Australian Journal of Science, 27, 263–264.

1980. Relationships amongst the fast-growing rhizobia of *Lablab purpureus*, *Leucaena leucocephala*, *Mimosa* spp., *Acacia farnesiana*, and *Sesbania grandiflora* and their affinities with other rhizobial groups. Journal of Applied Bacteriology, 49, 39–53.

Upadhyay, V.S., Rekib, A., and Pathak, P.S. 1974. Nutritive value of *Leucaena leucocephala* (Lam.) De Wit. Indian Veterinary Journal, 51: 534–537.

Van Den Beldt, R.J., Brewbaker, J.L., Hu, Ta-Wei, and Boontawee, Boonchoob. 1982. International leucaena population trials. Leucaena Research Reports, 3, 96–99.

Venketeswaran, S., and Romano, E.J. 1982. Tissue culture of forest trees for biomass energy production through in vitro propagation. Paper prepared for the International Congress on Plant Tissue and Cell Culture, Tokyo, Japan, July.

Vohradsky, F. 1972. Observations on influence of feeding horse tamarind (*Leucaena glauca* Benth.) on the health of cattle in Ghana. Ghana Journal of Agricultural Science, 5, 153–156.

Wahyuni, S., Yulianti, E.S., Komara, W., Yates, N.G., Obst, J.M., and Lowry, J.B. in press. Performance of Ongole cattle offered either natural grass, sundried *Leucaena leucocephala* or various proportions of each. Tropical Animal Health and Production (in press).

Wang, Tze-Ting, Tai, Kuang-Tao, Kiang, Tao, and Hu, Ta-Wei. 1982. Cultivation and production of leucaena. Taipei, Taiwan, CAPD (Council for Agricultural Planning and Development), Forestry Series 2. 54 p. (in Chinese).

Wildin, J.H. 1980. Management system for *Leucaena*. Queensland Agricultural Journal, 106, 194–197.

Williams, J. St.J., Low, M.T., and Jones, N. in preparation. Computerisation of data: an examination of in-breeding of *Acacia mangium* in Sabah. Sabah, Malaysia, Forestry Research Centre, FAO-UNDP-Project MAL 78/009, Working Paper 14.

Wilson, W.O., Abbott, H.K., and Abplanalp, H. 1961. Evaluation of *Coturnix* (Japanese quail) as pilot animal for poultry. Poultry Science, 40, 651–657.

Wong, C.C., Chen, C.P., and Ajit, S.S. in press. Assessment of *Leucaena leucocephala* introduction in Peninsular Malaysia. MARDI Research Bulletin (in press).

Wong, C.C., Izham, A., and Devendra, C. 1980. Agronomic performance and utilization of *Leucaena leucocephala* cv. Peru in Peninsular Malaysia. Proceedings, First Asian Australian Animal Science Congress, 369–374.

Wyatt-Smith, J. 1963. Manual of Malayan silviculture for inland forest. Kuala Lumpur, Malaysia, Forest Department.

Xu Yanqian, and Huo Yingqiang. 1981. Preliminary report on the introduction and trial cultivation of new leucaena in Guangdong Province. Guangdong Forestry Science and Technology Bulletin, 2, 1–9.

Young, Chiu-Chung, and Chao, Chen-Ching. 1982. Selection of *Rhizobium* of *Leucaena leucocephala*. Leucaena Research Reports, 3, 70.

Appendix. Economically Important Nitrogen-Fixing Tree Species[a]

	Origin	Chromosome number (2n)	Mature height (m)	Shape	Uses	Adaptation	Comments
Acacia (Mimosoideae; Leguminosae)							
A. albida	Africa, Israel	26	20	Leafless in rainy season	Forage (pods, foliage); shade	Dry tropics, Sahel, ~300 mm rainfall	Slow growth
A. auriculiformis	Australia; New Guinea	26	30	Spreading	Fuelwood, pulpwood (specific gravity 0.68, annual production 15 m^3/ha)	Widely adapted, humid tropics, ~750 mm rainfall, acid soils	Questionable tolerance to drought, fire, winds
A. confusa	Philippines, Taiwan	26	14	Spreading	Firewood (high specific gravity), ornamental	Wet subtropics, ~750 mm rainfall, acid soils	Slow growth
A. farnesiana	Tropical America	52	10	Often shrubby	Fuelwood; forage; tannin; perfume from flowers; ornamental, black dye for ink	Dry tropics, wide variety of soils	Very thorny; can be weedy
A. mangium	Australia; Papua New Guinea; Indonesia		30	Erect, stately	Timber (30 m^3/ha annually), firewood (specific gravity 0.65)	Moist tropics, ~1000 mm rainfall, acid soils (?)	Leaves often insect-infested, genetic variability
A. mearnsii	Australia	26	25	Spreading	Fuelwood (specific gravity 0.75), charcoal, tannins, dense wood (25 m^3/ha annually)	Moist subtropics, ~800 mm (?) rainfall, mid-elevation	Can be weedy
A. nilotica	Africa; India	52,104	~20		Firewood, charcoal, fodder (pods, leaves), source of tannin, gum	Dry tropics (thrives under irrigation)	Extremely thorny, variable
A. saligna	West Australia		~7	Shrub, small tree	Fodder, fuel, sand-dune fixation, source of tannin, recolonization of mining areas, erosion control, ornamental	Humid to subhumid tropics, ~300–1000 mm rainfall, sandy, swampy sites	Rapid growth outside native areas tolerant to drought, salt, winds, fire, can be weedy
A. senegal	Africa; Pakistan, India	26	~13	Often shrubby	Firewood, charcoal (~5 m^3/ha annually), gum arabic, feed (pods, foliage)	Dry tropics, ~200 mm rainfall, poor soil, hot climates	Extremely thorny, can be weedy
A. tortilis	Africa; Sahel, Israel, Arabia		~15	Often shrubby	Firewood, dense, fodder (pods, leaves)	Dry tropics, ~100 mm rainfall, hot climates, alkaline soils	Thorny, lateral roots, heat tolerant

***Albizia* (Mimosoideae; Leguminosae)**							
A. falcataria	Indonesia, Papua New Guinea		·45		Pulpwood, soft (specific gravity 0.33), moldings, boxes, soil improvement	Moist tropics, ·1000 mm rainfall, midlands	Soft wood, poor fuel
A. lebbek	Tropical Asia, Africa	26	·30		Fuelwood (high value, 5200 kcal/kg), foliage for feed (5 m^3/ha annually), furniture	Widely adapted, dry, moist tropics, ·600 mm rainfall	Slow growth
***Alnus* (Betulaceae)**							
A. acuminata	Central America		25		Firewood (specific gravity 0.5), timber (15 m^3/ha annually), shoes	Cool, tropic highlands to 3000 m, ·1250 mm rainfall	Not heat, drought tolerant
A. glutinosa	Europe to West Asia, Asia Minor to North America	28	40		Energy production (fuel, specific gravity 0.52), soil stabilization (riverbanks, roadsides, mine wastes), shoes	Widely adapted, temperate, subtropical, to 500 m	Not drought tolerant
A. nepalensis	Himalayas	28	30		Firewood (specific gravity 0.35), utility timber	Cool tropic highlands to 3000 m, mesic, ·800 mm (?) rainfall	Soft wood, susceptible to some insects
***Calliandra* (Mimosoideae; Leguminosae)**							
C. calothyrsus	Central South America	22	10	Shrubby	Firewood (specific gravity 0.65, 40 m^3/ha annually), forage (high tannin), green manure	Moist tropics, ·1000 mm rainfall, cool areas, above 500 (?) m	
***Casuarina* (Casuarinaceae)**							
C. cunninghamiana	Australia	18	35		Firewood (specific gravity 0.7), shade, riverbank stabilization	Cool tropics to warm temperate, ·500 mm rainfall	Can be weedy (Florida)
C. equisetifolia	Australia, Pacific Islands to India		35		Firewood (specific gravity 1.0), charcoal, windbreak, timber for posts	Warm tropics, coastal areas	Coppices poorly, typhoon tolerant, very saline tolerant
C. glauca	Australia, New South Wales to Queensland		20		Firewood (specific gravity 0.98), charcoal, fencing, piles for seawater, windbreaks in coastal areas	Warm temperate to subtropics, coastal areas, heavy clay soils	Produces root suckers and can be weedy (e.g., Florida), salt-tolerant

Appendix continued

Appendix Continued

	Origin	Chromosome number (2n)	Mature height (m)	Shape	Uses	Adaptation	Comments
C. junghuniana	Indonesia		30		Firewood, charcoal, poles, pilings	Tropical lowlands, midlands, forming dense forests	Little studied; male clone (or hybrid) widely used in Thailand; wood easily split; wide pH tolerance, moderate drought tolerance
***Dalbergia* (Papilionoideae; Leguminosae)**							
D. sissoo	Indian sub continent	20	30		Lumber, fuelwood (specific gravity, 0.68)	Warm tropics, mesic, arid, 500 mm rainfall	Slow growth (fast by *Dalbergia* standards)
***Erythrina* (Papilionoideae; Leguminosae)**							
E. berteroana	Tropical America	42	10	Small crown	Live fence, forage, windbreaks	Lowland, submontane, moist tropics to 2000 m, usually in wetter areas but needs good drainage	Fast growth, resistant to wind, soft wood that accepts wires and nails well, easily cloned
E. fusca	Central South America	42	30	Broad crown	Shade for coffee and cocoa, live fence, soft wood, green manure	Lowland, moist tropics to 1500 m, often in swamps or on poorly drained clayey soils	Fast growth, easily cloned
E. poeppigiana	South America to Panama	42	40		Shade for coffee, ornamental, soft wood, paper pulp, forage, mulch	Dry, to mesic tropics to highlands	Fast growth, easily coppiced and cloned
***Gliricidia* (Papilionoideae; Leguminosae)**							
G. sepium	South Central America	20	10		Firewood (specific gravity, 0.75), timber, 8 m³/ha annually, fodder, shade, ornamental, live fence	Dry to humid tropics, 1000 mm rainfall, saline soils	Toxic bark, seeds, root, aphids on foliage, easily propagated by cuttings

***Inga* (Papilionoideae; Leguminosae)**							
I. vera	Caribbean, Central America		20		Shade for coffee, fuelwood (specific gravity 0.75), timber, shade, honey production	Humid tropics, <1000 mm (?) rainfall, lowlands	Little studied, relatively fast growth
***Intsia* (Caesalpinioideae; Leguminosae)**							
I. bijuga	Southeast Asia, East Africa, India	24	40	Buttressed	Timber, decking	Moist tropics, >2000 mm (?) rainfall	Genetic variability highly resistant to rot, slow growth
***Leucaena* (Mimosoideae; Leguminosae)**							
L. diversifolia	Central America	52	18		Fuelwood (specific gravity 0.5), shade, forage	Dry to mesic tropics, <500 mm rainfall, to midlands (1500 m)	Little studied great genetic diversity, shrubby variants
L. leucocephala	Central America, Mexico	104	18		Fuelwood (specific gravity 0.55, 50 m^3 ha annually), nurse tree forage, small timber, pulpwood, food (pods, seeds, leaves), energy plantations	Dry to mesic tropics, <500 mm rainfall, lowlands	Widely studied, shrubby variants
***Mimosa* (Mimosoideae; Leguminosae)**							
M. scabrella	Southeast Brazil, Argentina		12	Thornless	Fuelwood, pulpwood, ornamental, shade for coffee	Mid elevation, cool tropics, subtropics (flourishes at 2400 m Guatemala)	Little studied, rapid growth
***Parkia* (Mimosoideae; Leguminosae)**							
P. roxburghii	Indo-Malaysia, Philippines		40	Umbrella crown	Timber, ornamental, seeds used in local medicine	Humid tropics, <1000 mm (?) rainfall, 500–700 m elevation widely pantropical	Pest tolerant, protected in Indonesia
P. speciosa	Thailand, Malaysia		15	Thin crown	Food (seed from large pods)	Humid tropics, to 1500 m elevation	Seeds often insect infested, slow growth, hybridizes with *P. roxburghii*

Appendix continued

Appendix. Concluded

	Origin	Chromosome number (2n)	Mature height (m)	Shape	Uses	Adaptation	Comments
***Parkinsonia* (Caesalpinioideae; Leguminosae)**							
P. aculeata	Americas	28	20	Spreading	Fuelwood, fodder, ornamental, fences, local medicine	Widely adapted to moist, dry tropics, sandy, saline soils	Very thorny, weedy in Argentina
***Pithecellobium* (Mimosoideae; Leguminosae)**							
P. dulce	Central South America	26	20	Irregular and untidy spreading tree	Fuelwood (5500 kcal/kg), forage, construction post-wood, shade (thorny hedges), food (pods), tannin, oil (seeds)	Dry to mesic tropics to cooler elevations (south Florida)	Thorny (segregating), poor form, smokey fuel
***Pongamia* (Papilionoideae; Leguminosae)**							
P. pinnata	Indian subcontinent; Malaysia; China; Tropical Asia;		8		Firewood, fodder (leaves), oil (seeds), pest control (leaves) shade, medicine	Mesic tropics, ~600 mm rainfall, saline soils	Aggressive, spreading roots, also known as *Derris indica*, grows to full height in 5 years
***Prosopis* (Mimosaceae; Leguminosae)**							
P. alba–chilensis complex (*P. alba*, *P. chilensis*, *P. flexuosa*, *P. nigra*)	Argentina; Paraguay; Chile; South Peru	28	15		Firewood, timber (12 $m^3 \cdot ha$ annually), fodder (pods)	Cool, dry subtropics, ~200 mm rainfall, to 3000 m in Peru	Thorny (segregating)
P. cineraria	India		9	Thorny, spreading	Firewood, charcoal, fodder, timber, green manure (yields to 3 $m^3 \cdot ha$ annually under drought stress)	Dry, hot tropics, ~100 mm (?) rainfall	Thorny (segregating), weedy

P. pallida – juliflora complex (*P. pallida*, *P. juliflora*)	Central, northern South America	26.52.5b	15		Firewood (specific gravity 0.8), charcoal fodder (pods), honey production, timber (5 m³ ha annually)	Dry, hot tropics, ~200 mm rainfall	Thorny (segregating), often weedy (*P. glandulosa*, *P. velutina* are the mesquites of southern USA and elsewhere in the tropics, often labeled *juliflora* in error), deep roots, frost-tolerant
P. tamarugo	Chile		15		Firewood (high specific gravity), forage (pods, leaves)	Dry, hot, saline tropics, ~10 mm rainfall	Slow growth, thorny (?), remarkable saline tolerance
***Pterocarpus* (Mimosaceae; Leguminosae)**							
P. indicus	Southeast Asia, Indochina, Pacific Islands	22	40	Broad crown, lofty	Timber (na: ...), ornamental, furniture, flooring	Moist tropics	Needs deep soil, some diseases, relatively fast growth
***Robinia* (Papilionoideae; Leguminosae)**							
R. pseudoacacia	Northeast America	20,22,24	25		Fuelwood (dense), erosion control, nurse tree, posts (20 m³ ha annually), forage	*Temperate regions*, highland tropics	Little studied
***Samanea* (Mimosoideae; Leguminosae)**							
S. saman	Central, South America, Mexico	26	40	Wide spreading	Shade, timber (specific gravity 0.52), craftwood, food (pods), ornamental	Mesic to wet tropics ~600 mm rainfall	Not good hardwood, rapid growth
***Sesbania* (Papilionoideae; Leguminosae)**							
S. grandiflora	India to Southeast Asia	14,24	10	Slender	Pulpwood (specific gravity 0.42), forage (leaves, pods), food (flower, leaves, young pods), ornamental (22 m³/ha annually)	Moist tropics, ~1000 mm rainfall, onto poor soils	Genetic variability, soft wood, borer susceptibility, large nodules

* Brewbaker, J.L., and Styles, B.T., ed. 1982. Waimanalo, Hawaii, USA: Nitrogen Fixing Tree Association.

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